Outline

- Beta-beat from warm quadrupoles; dependence on working point
- Beta-beat with space charge
- Lattice optimization/correction (without and including space charge)
- Verification of correction by tracking (in progress)

Definitions

- Here I define beta-beating (β-beat) as a function of s

$$100 \cdot \Delta\beta(s)/\beta(s) = 100 \cdot (\frac{\beta_{perturbed}(s)}{\beta_{ideal}(s)} - 1) \quad [\%]$$

- beta-beating indicates the breaking of ring symmetry
- the level of beta-beating as a single number $100 \cdot std(\Delta\beta/\beta) \quad [\%]$

We consider here corresponding perturbations

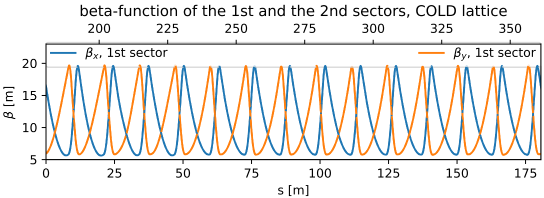
- Localized perturbation as the pair of warm (long) quadrupoles
- space charge (SC) as additional defocusing (in terms of distributed linear kicks)
- Distributed random gradient errors (in progress)

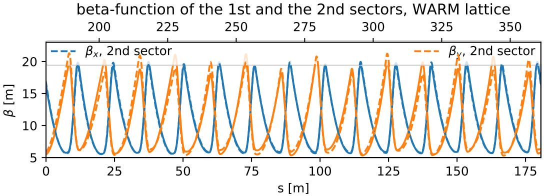
LQD = 1.3 m, L52QD = 1.73 m, Corresponding integral field strengths:

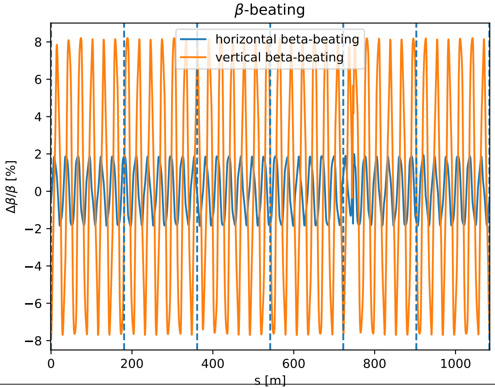
kw1 = 1.0139780 * kd
kw2 = 1.0384325 * kf

(Q_x, Q_y)=(18.84,18.73), no space charge

The level of beta-beating is $\sigma(\Delta\beta/\beta) \simeq 7\%$

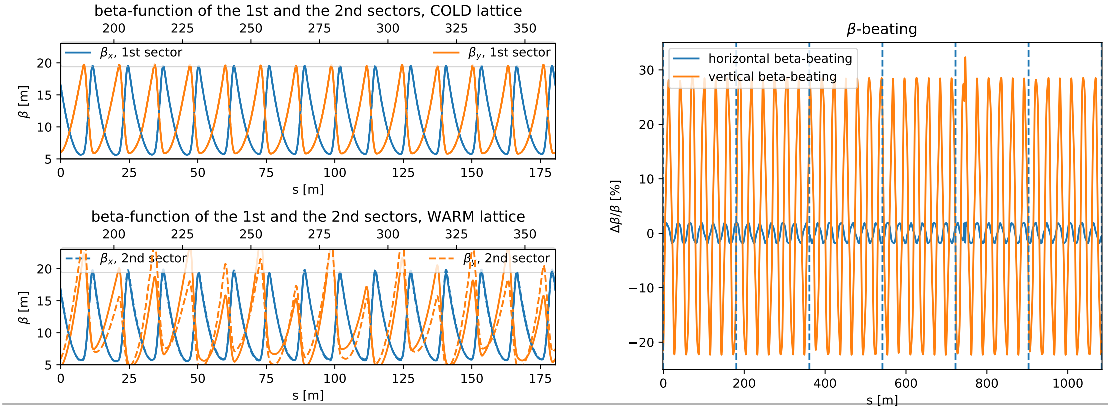






(Q_x,Q_y)=(18.84,18.55), no space charge

Beta-beating increases towards the vertical half-integer stopband, $\sigma(\Delta\beta/\beta) \simeq 18\%$



What happens if we add space charge?

Nominal U28 beam
Np=5e11
ϵ_x, ϵ_y = 35 mm mrad, 15 mm mrad
$(\Delta p/p)_{rms}$=0.5e-3

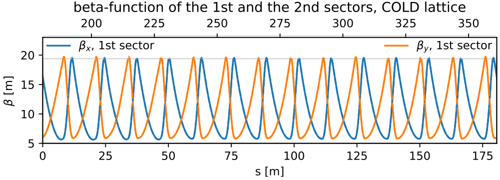
With these parameters we have space charge perveance

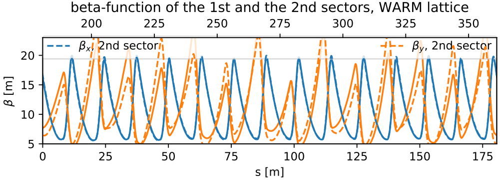
$$Ksc = 3.3e - 8$$

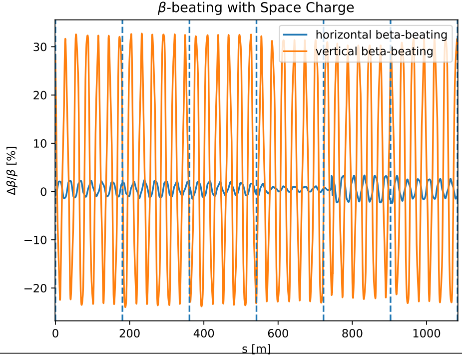
Incoherent vertical KV tuneshift dQkv = 0.15
With the corresponding maximum of vertical gaussian tunespread dQgauss = 0.3

(Q_x, Q_y)=(18.84,18.55), space charge applied

Envelope Solver provides beta-function calculations for the given perveance, $\sigma(\Delta\beta/\beta) \simeq 19\%$
Ksc = 3.3e-8 with $\Delta Q_{y,KV} = 0.15$

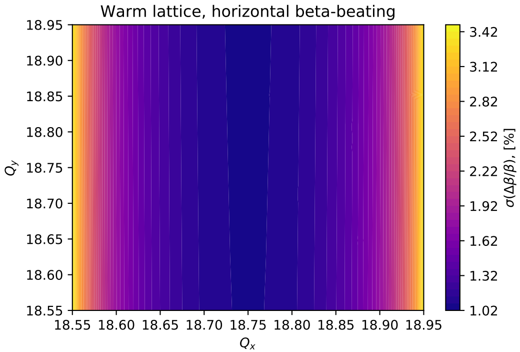


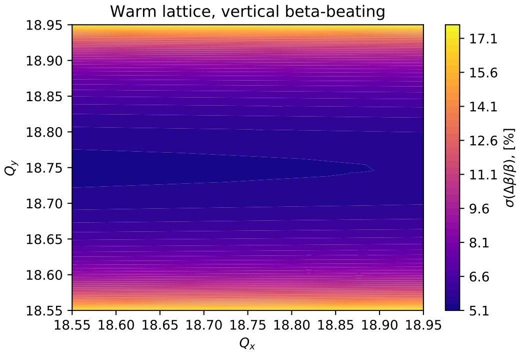




Warm quads perturbation without space charge

The level of beta-beat indicates half-integer stopbands. Different scales!



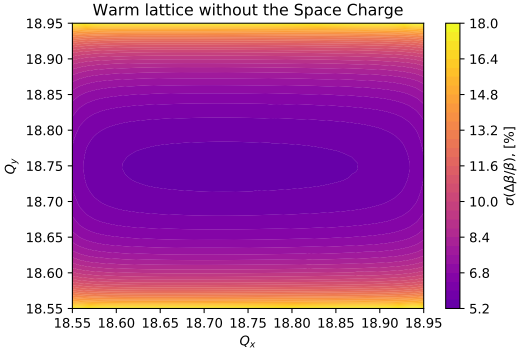


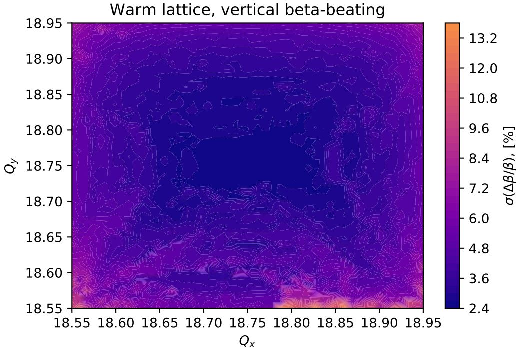
Used fixed setup:
kw1 = 1.0139780 * kd
kw2 = 1.0384325 * kf

What if we try to tune the settings of the warm quadruples?

Optimization of the warm quads settings, no SC

Computed on Kronos. We can reduce beta-beating for the case without space charge





Optimization

The implemented approach is the observable minimization constrained by (Qx,Qy)

- Observables
  - $Max(FFT(\beta_{perturbed} - \beta_{cold}))$
  - $\sum(FFT(\beta_{perturbed} - \beta_{cold}))_{aperiodic}$
  - $std(\Delta\beta/\beta)$
- Methods
  - COBYLA (Constrained Optimization BY Linear Approximation)
  - trust-constr (to be done)
  - SLSQP (Sequential Least SQuares Programming) (doesnt seem robust for our approach)
- What do we use to optimize the lattice?
  - the settings of the pair of warm quads
  - Correctors (the case of non-zero gradient errors, to be done)

Kronos

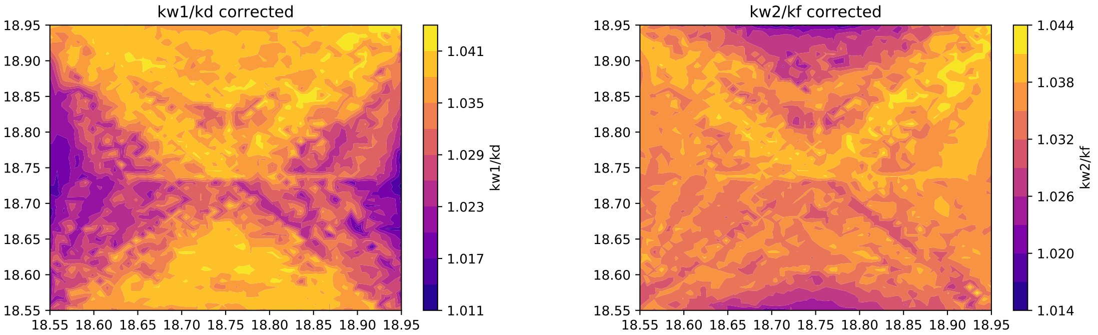
Kronos (GSI cluster) is a Portable Batch System

- The optimization of one working point takes from 10 to 120 minutes, which is comparable to my laptop
- The full scan takes $2500 \cdot 20\ mins/n_{CPU}$ on my laptop
- The full scan on Kronos takes less than 30 minutes for the majority of points
- Doesn't produce any noise in my room

- envelope solver
- py-orbit

Optimized parameters. Without space charge

The settings of the warm quads depend on the working point
Initial settings: kw1/kd=1.013 and kw2/kf=1.038

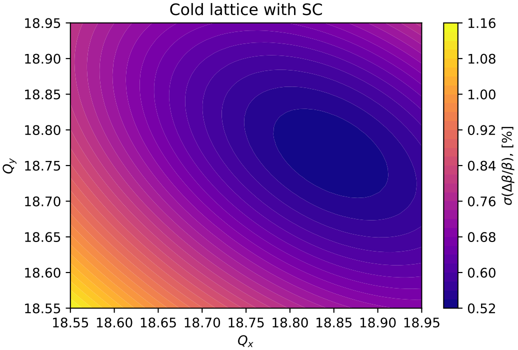


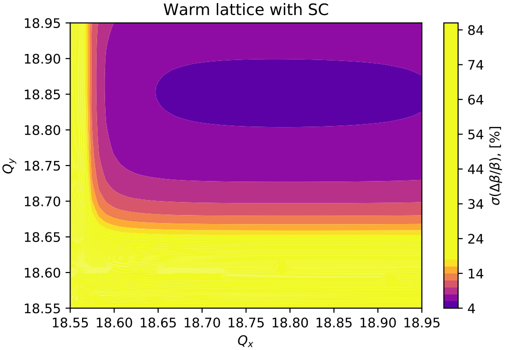
What happens if we include space charge to the optimization scheme?

Cold (reference) lattice vs the warm lattice with space charge

Ksc = 3.3e-8 with $\Delta Q_{y,KV} = 0.15$

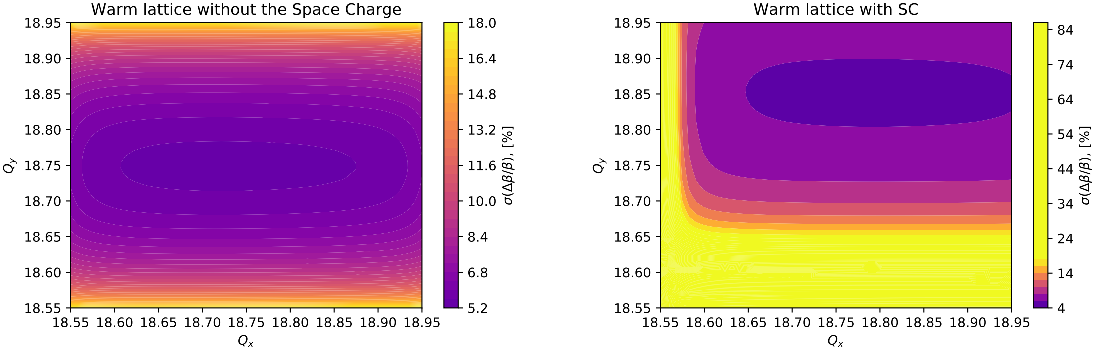
Different scales!





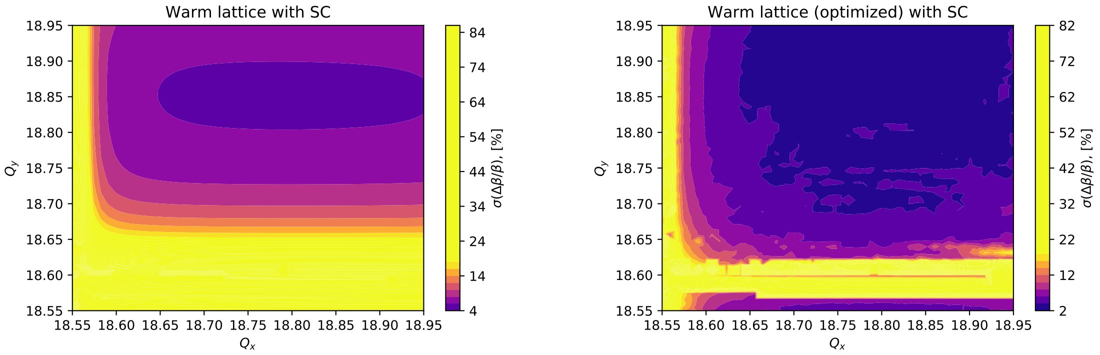
Warm lattice with space charge

Ksc = 3.3e-8 with $\Delta Q_{y,KV} = 0.15$, coherent tuneshift $\Delta Q = 0.1$

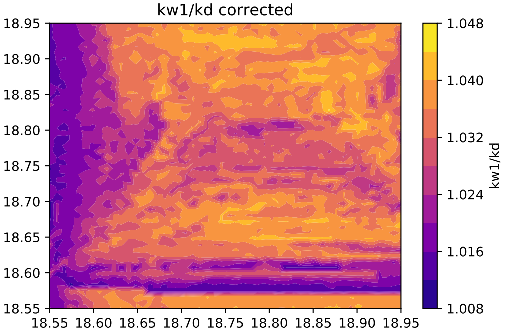


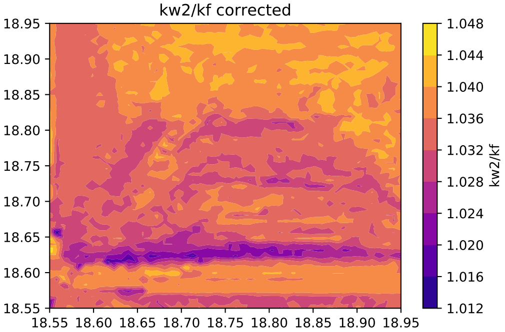
Optimization with the SC included

Ksc = 3.3e-8 with $\Delta Q_{y,KV} = 0.15$, coherent tuneshift $\Delta Q = 0.1$



Optimization with the SC included





Verification of the optimization

The verification process is based on the tracking of the beam distribution in the lattice before and after the optimization.

- py-orbit (now is ready on Kronos)
- 2D, 2.5D space charge
- the case of gradient errors requires the binding with MADX error tables (to be implemented)

The current plan is to optimize the warm lattice (with and without SC) using Envelope Solver, transfer the settings to py-orbit, set up the tracking and compare beam sizes (as losses also) after sufficient number of turns.

Conclusions

- The level of beta-beating depends on the working point and SC
  - Envelope Solver provides SC-dependent beta-functions computations on Kronos (done)
  - It’s possible to receive the information about SC-dependent beta-functions from the tracking. (planned)
- The level of beta-beating indicates the location and the width of the half-integer stopbands
  - Compare with analytical prediction of the stopband width (to be done)
- The settings of the warm quadruples can be optimized
  - Without SC (done)
  - Including SC (done)
  - Including random gradient errors + correctors (planned)
  - Including random gradient errors + correctors + SC (planned)
- The verification of the optimization
  - tracking (to be done)