LEL 2022: 3rd Workshop on low emittance lattice design
ALBA laboratory, 26-29 June 2022

ESRF-EBS: lessons learned

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(and the Beam Dynamics group)

ESRF | The European Synchrotron

OUTLINE

Accumulation

- **Sextupole tunings**
- **Obstacles search**

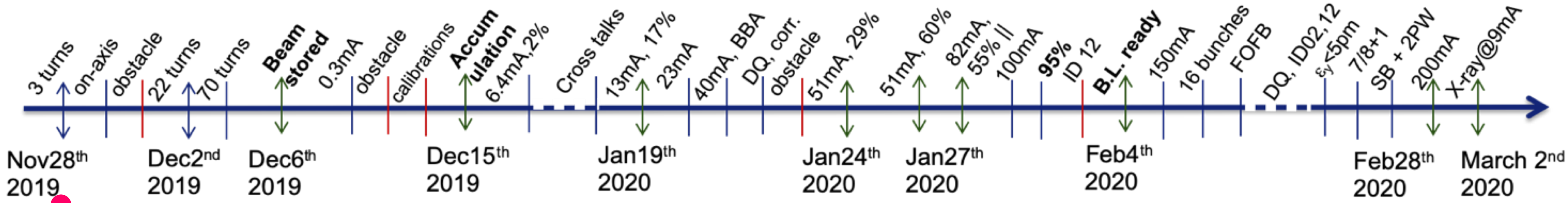
Optics

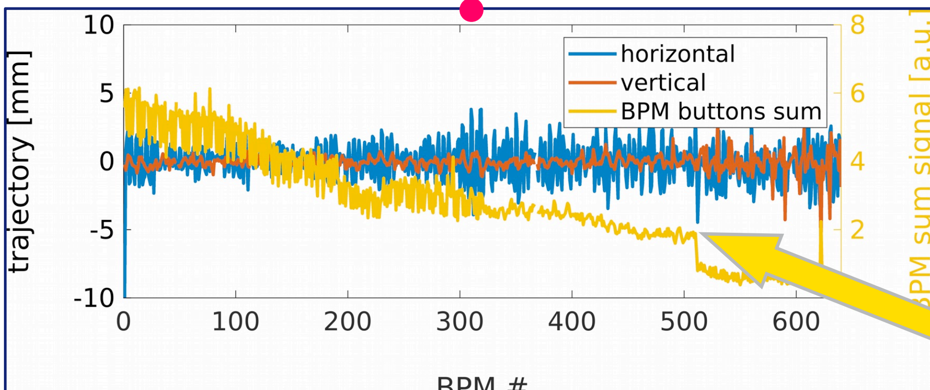
- **Magnet calibration**
- **Cross talk**
- **Closed orbit correction**

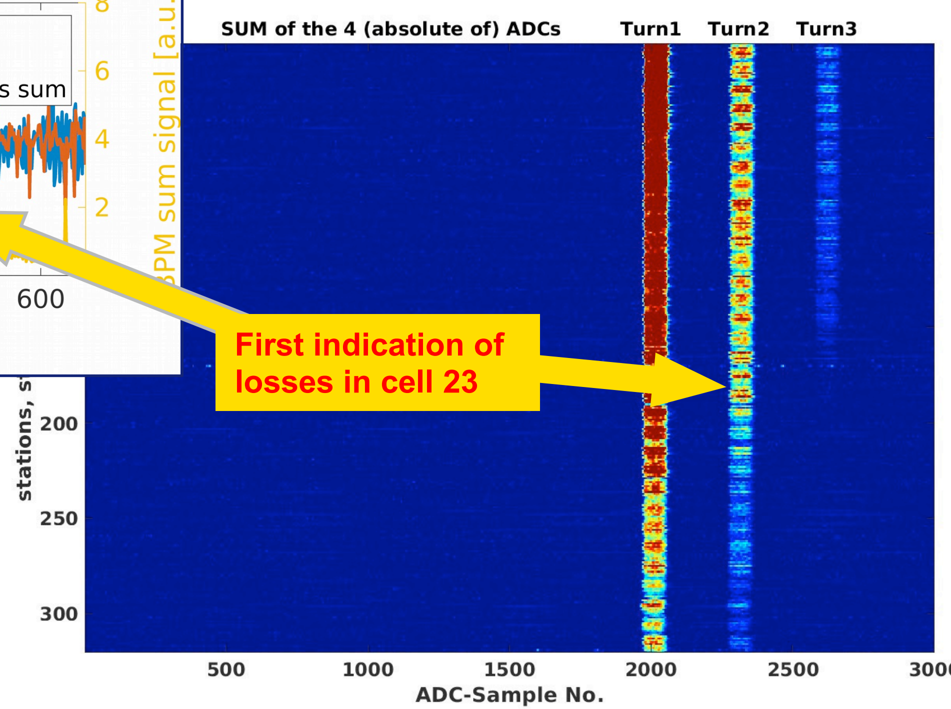
Operation

- **Nonlinear dynamics optimization**
- **Emittance exchange in the booster**

FIRST TURNS





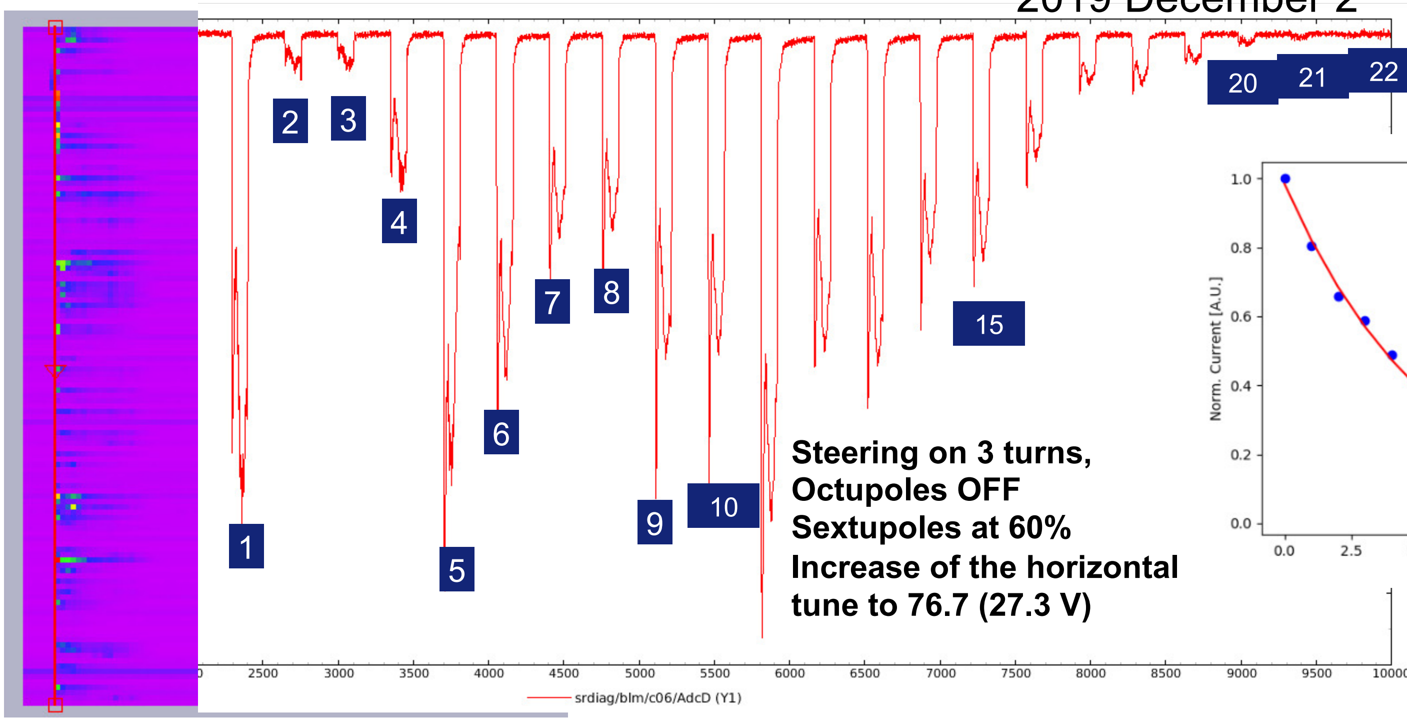


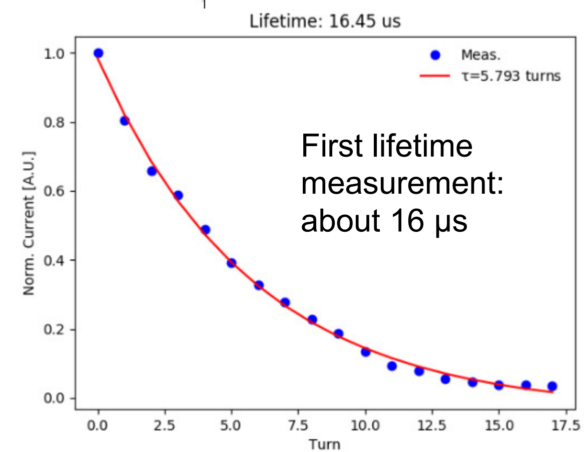
November 28th:
First 2.5 turns obtained without any steering in the storage ring
First indication of obstacle in the vacuum chamber

22 TURNS ON-AXIS

- After first obstacle removed. Off-axis to on-axis injection.
- First turns steering to maximize the number of turns.
- Sextupoles/octupoles scanned to have better capture.
- Not enough turns to store the beam.

2019 December 2nd

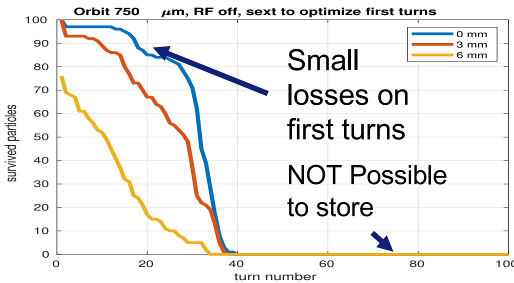




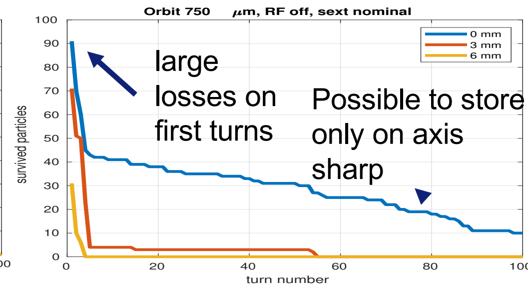
BEAM STEERED UP TO 80 TURNS, OPTIMAL SEXTUPOLES FOR ACCUMULATION

With just first turns correction, we had **750 um** trajectory (H, V). Not more than 40 turns.

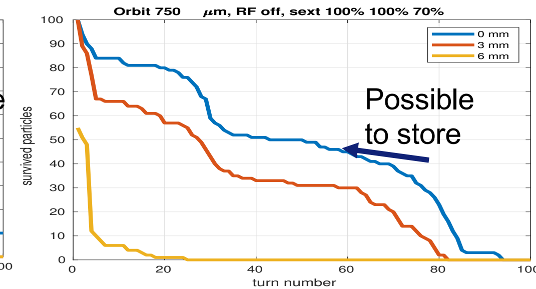
simulations



PRESENT SR SITUATION



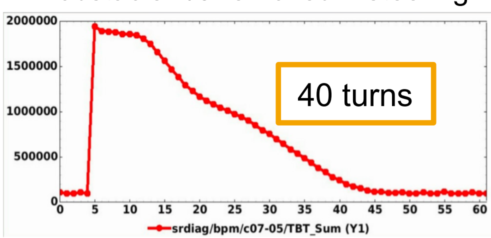
DESIGN LATTICE

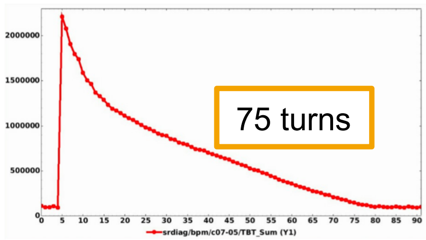


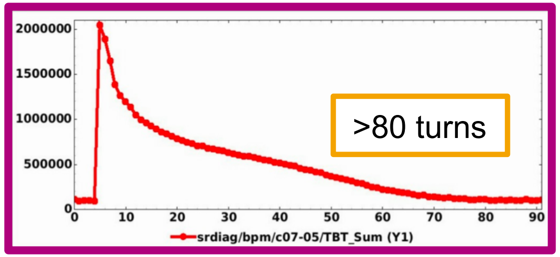
Optimized setting

measurement

obstacle 1/3 removed + steering



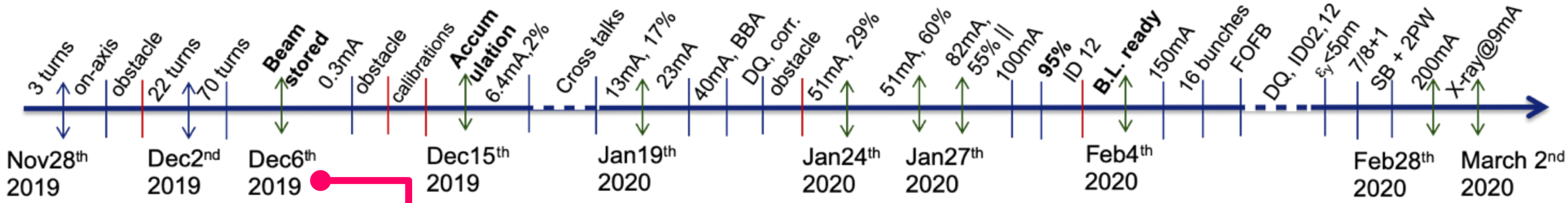


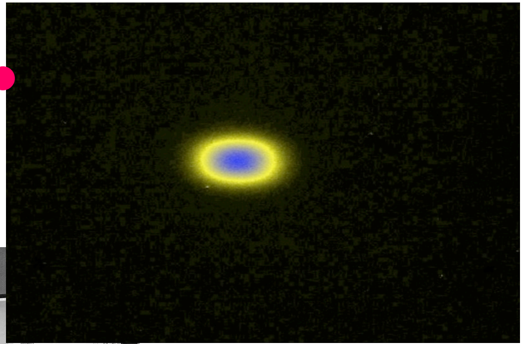


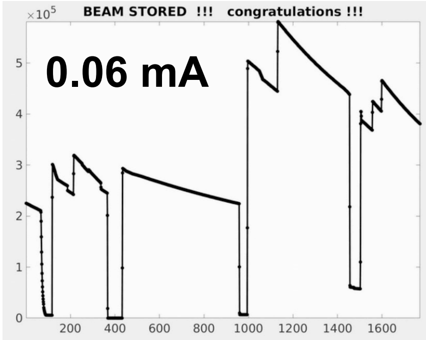
A different sextupole setting derived in simulation allowed to keep the beam for about 80 turns and so to store it once the RF is on.

Beam stored on December 6th with different sextupole setting.

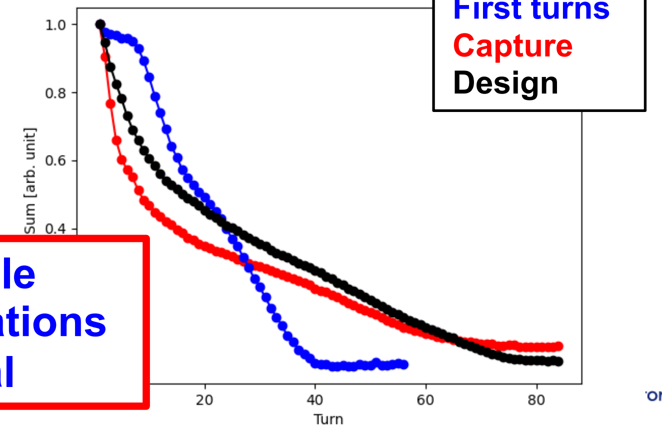
STORED BEAM





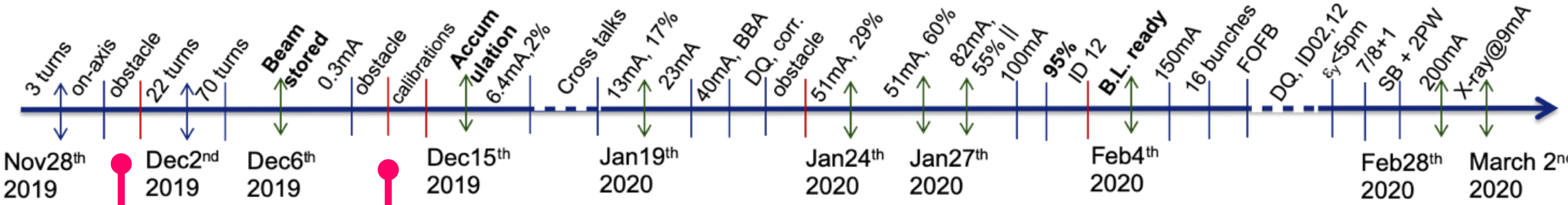


December 6th:
Beam stored and first light on the pinhole cameras

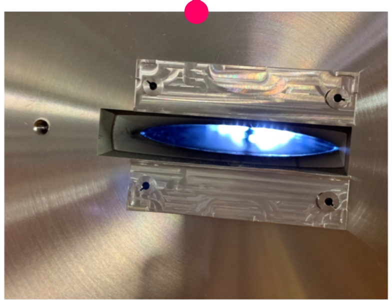


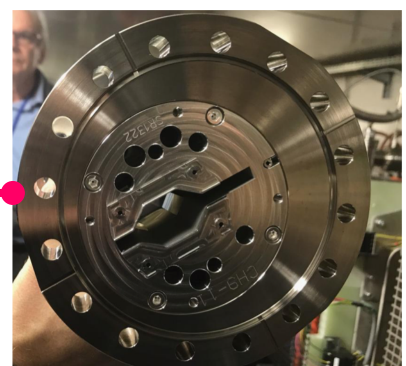
Sextupole optimizations essential

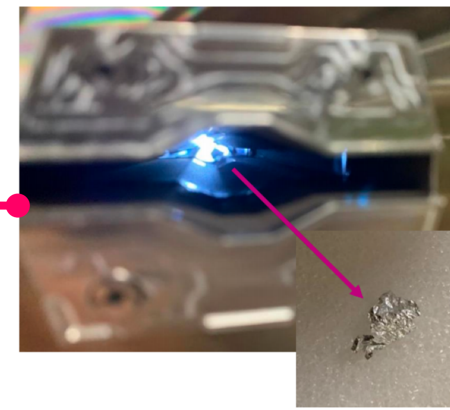
OBSTACLES



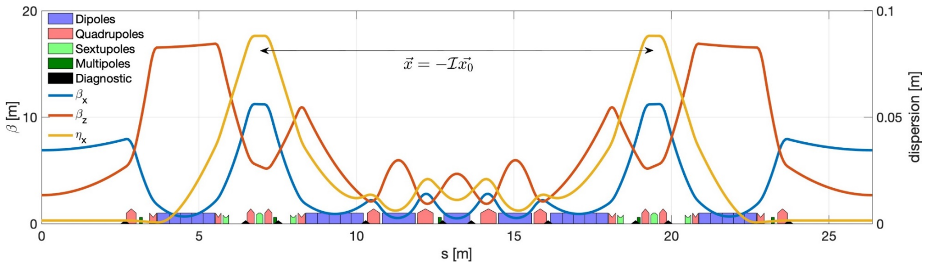
3 obstacles found in the vacuum chambers during the commissioning

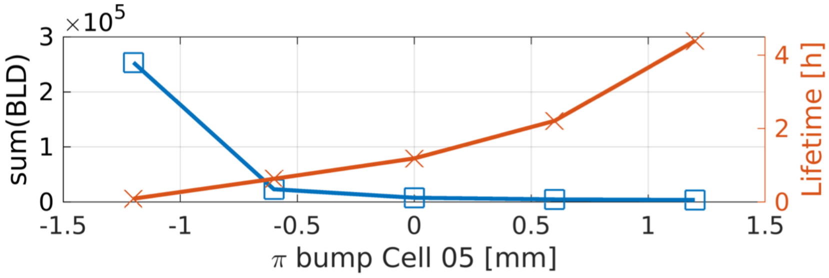


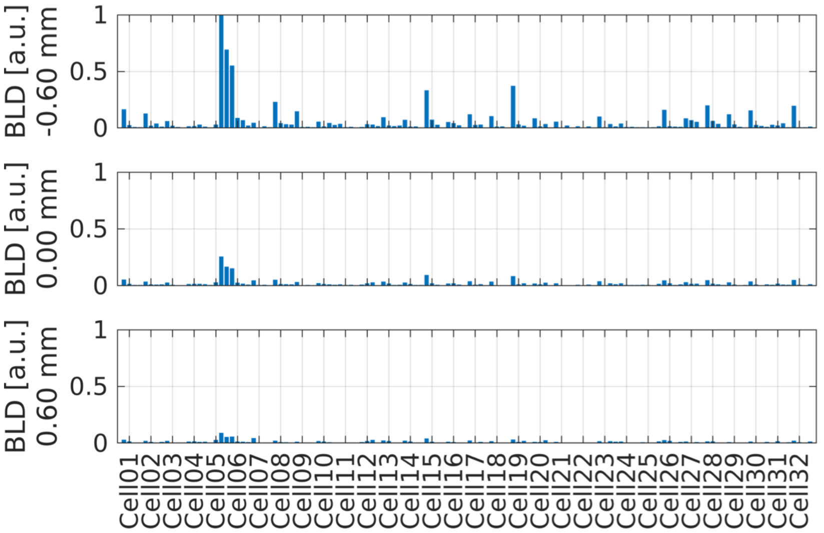




OBSTACLES DETECTION







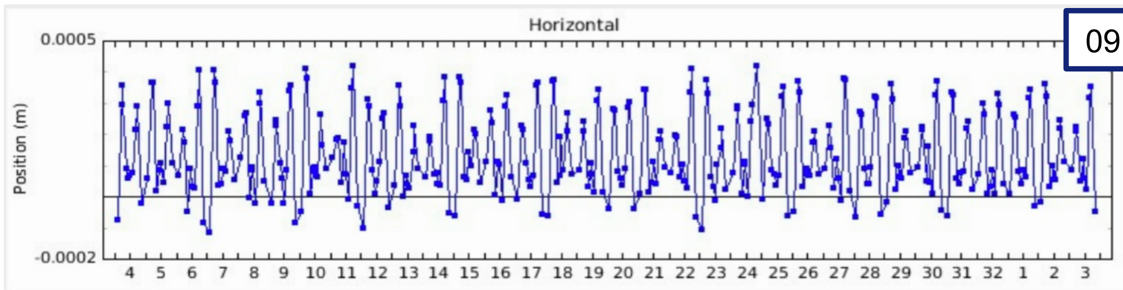
Bumps and beam loss detectors have been used a lot to locate the obstacles.

For obstacles located in the middle of the cell, π bumps were used.

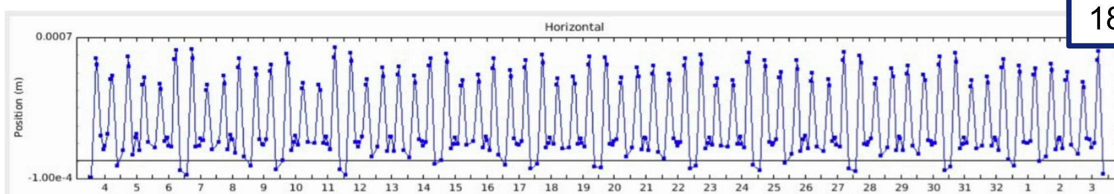
The exact location for the intervention is then found with activation measurements in the tunnel.

SEVERAL CALIBRATION SCALE FACTORS WRONGLY ASSIGNED

SEVERAL CALIBRATION SCALE FACTORS FOR QUADRUPOLES, SEXTUPOLES, DQ, OCTUPOLES WERE WRONG (>1% errors).



09 Dec 2019 first measurement



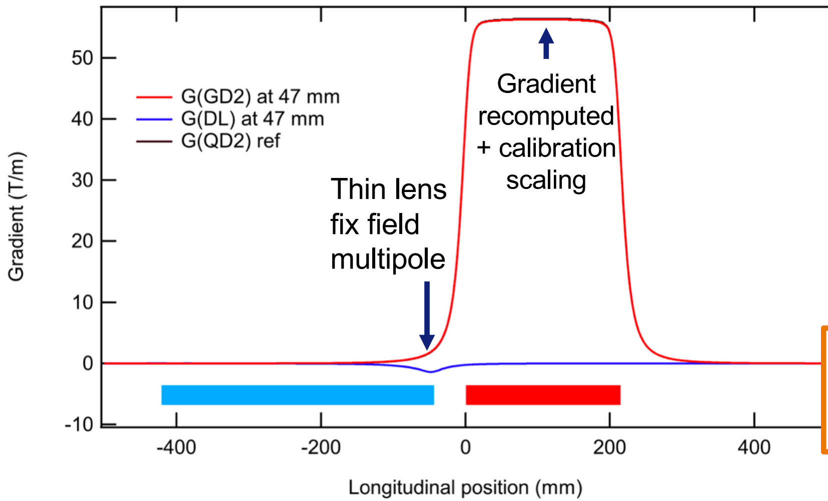
18 Jan 2019 first correction 2020

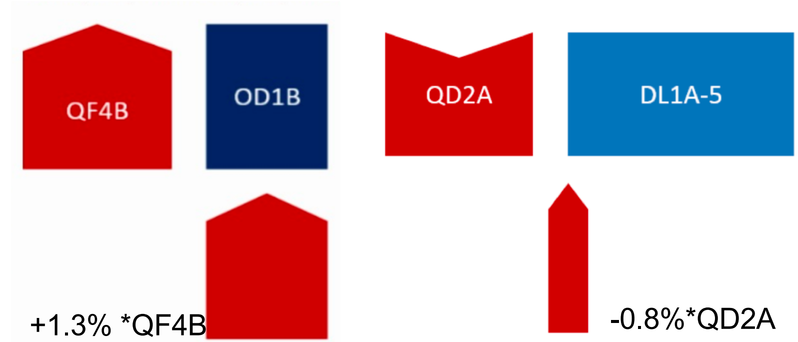
Different simultaneous layers of errors: signs, serial numbers, outliers, * or / by calibration. The simulator could have been used more to spot ahead some of these errors.

Once all the calibration errors were fixed, the optics was much better!

OPTICS DURING WINTER SHUTDOWN: CROSS TALK

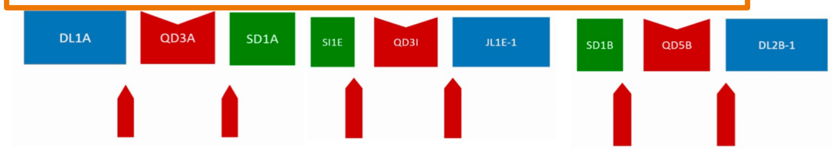
Magnetic simulations show a **cross-talk** effect among neighboring magnets.





model tunes:	76.2100	**27.3400**
+ Cross Talks:	76.6973	**26.0038**

-1.3 Q_y



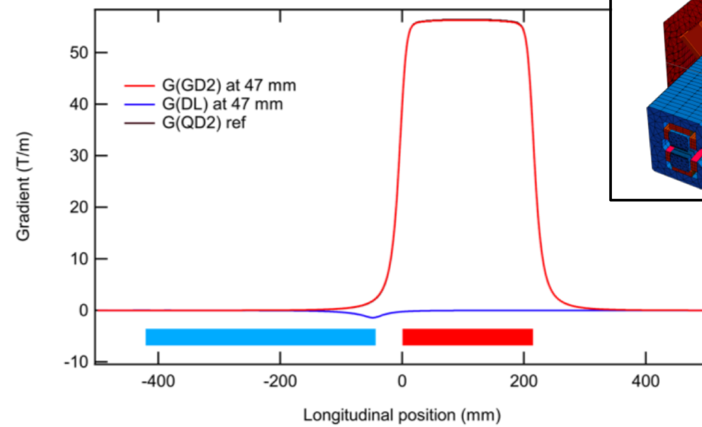
MAGNETIC MODEL

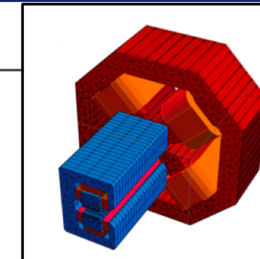
The machine started with significant errors in the magnetic modeling of the lattice, several sources identified:

Magnetic cross-talk between adjacent magnets:
- derivation of all cross-talk
- adapt model to include cross-talk as thin lenses, rematch lattice

Calibration factors wrongly assigned:
- full verification of all magnets
- control system debugged
- double check with factory measurements

Strong reduction of acceptance: without these it would have been possible to accumulate with design strength and off-axis injection

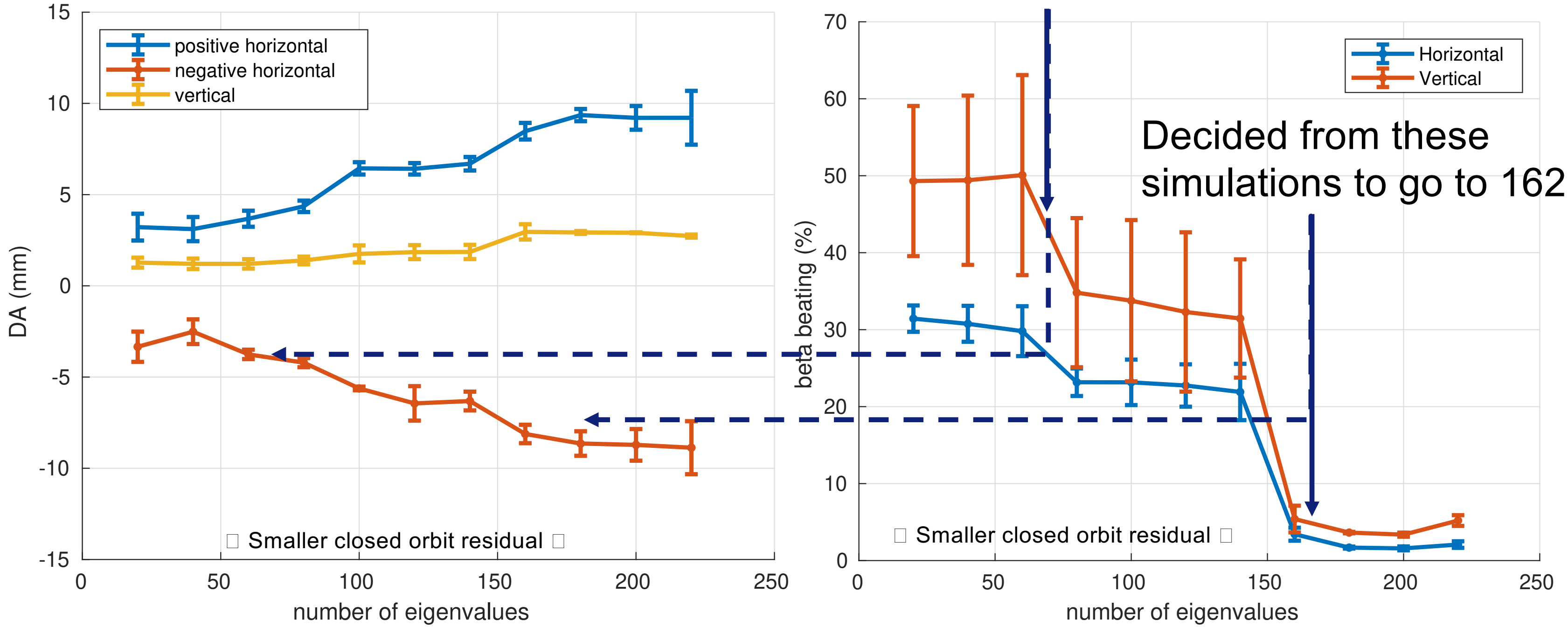




left magnet	main magnet	right magnet
	QD2 −0.088 % body	DL1A −0.792 % edge
DL1 −0.93 % edge	QD3 −0.141 % body	SD1 −0.342 % edge
	QF4 −0.03 % body	SF2 −0.27 % edge
SF2 −0.27 % edge	QF4 −0.03 % body	OD 1.7 % body
SD1 −0.274 % edge	QD5 −0.056 % body	DL2 −0.84 % edge
DL2 −0.02 % edge	QF6 −0.082 % body	DQ1B 0.04 % body
DQ1B 0.042 % body	QF8 −0.061 % body	

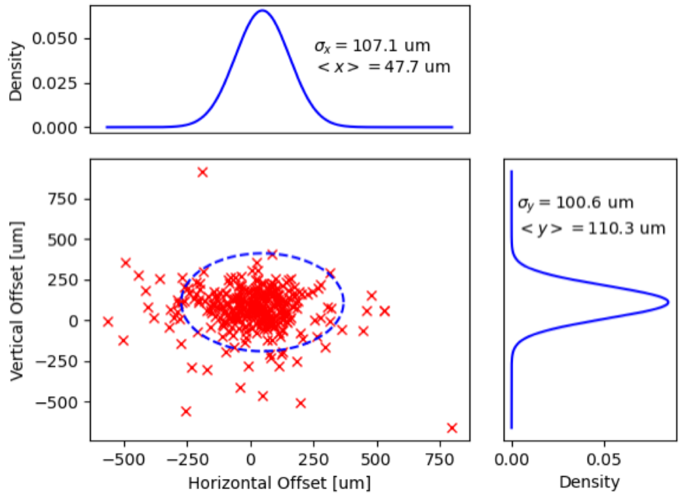
DA STUDIES: DA VS ORBIT CORRECTION

Initially we were using 64 eigenvectors

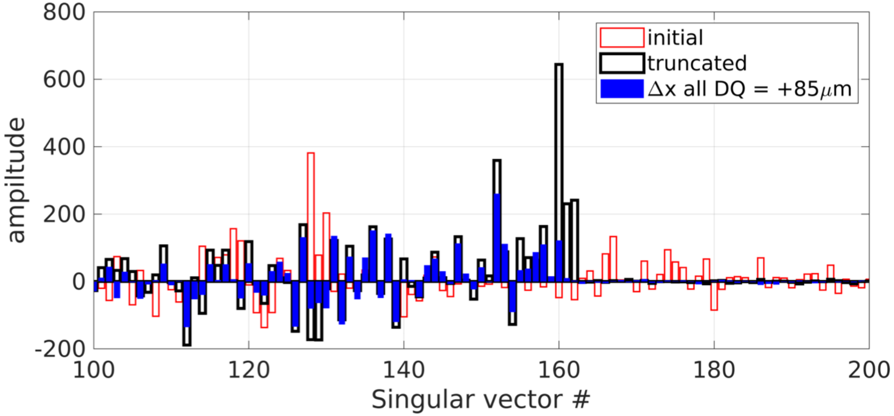


Correct more closed orbit: more eigenvectors, DQ steerers.

Beam based alignment results:
~100 µm rms offsets in both planes

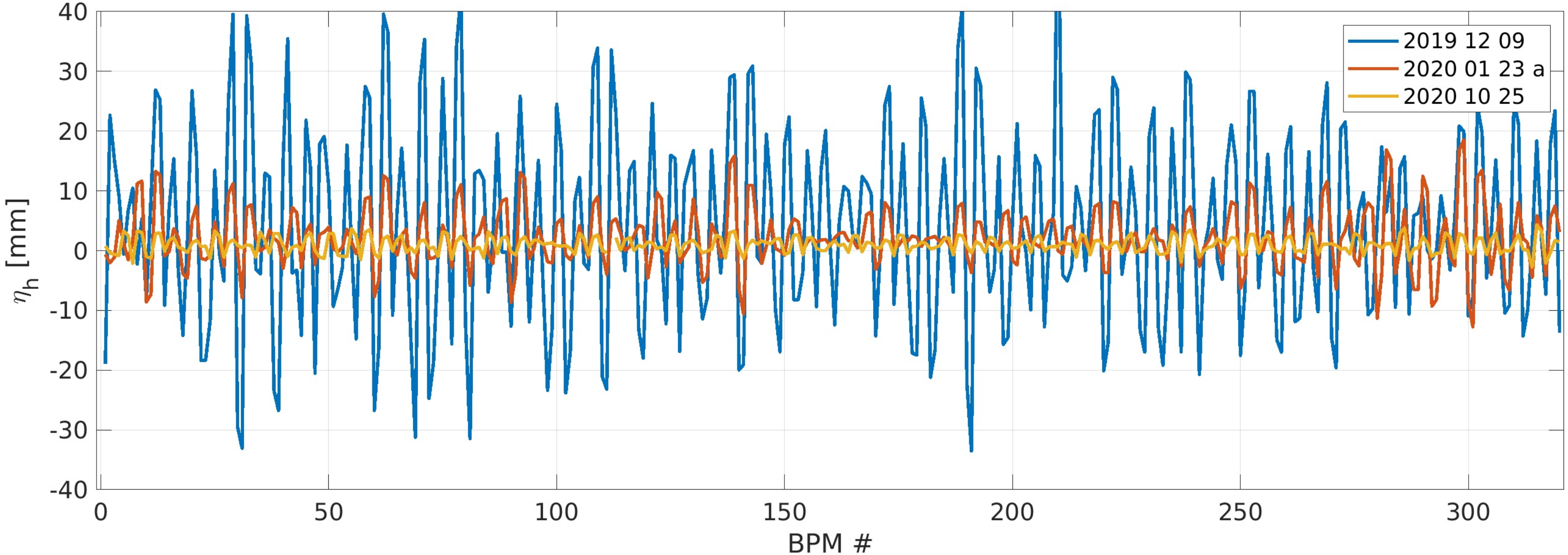


Eigen mode analysis:
demonstrated DQ missing angle due to calibration and alignment errors



Orbit corrections are done with 162 eigenvalues and we started to do SVD truncation

OPTICS CORRECTION

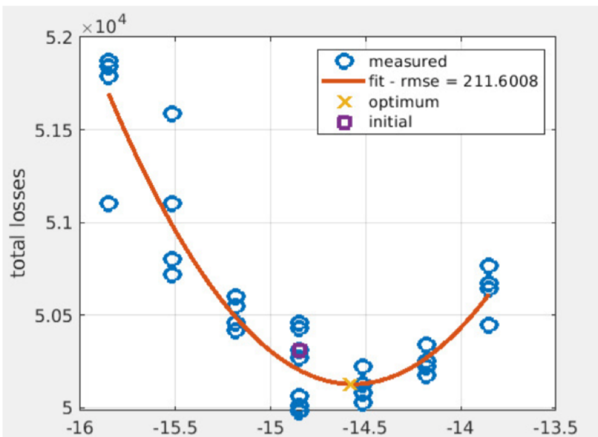


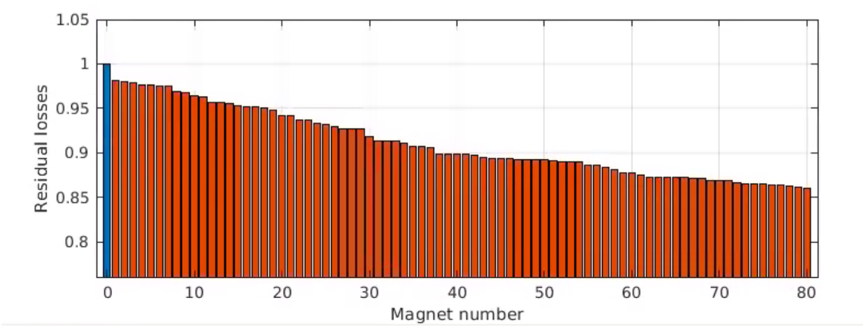
Dec 2020 ► Fixed calibrations, cross talks, steering with 162,128 singular values (more than foreseen), *BBA*, NO quadrupole correction (except tune) ► Jan 2020 "uncorrected" ► Optics correction ► Oct 2020

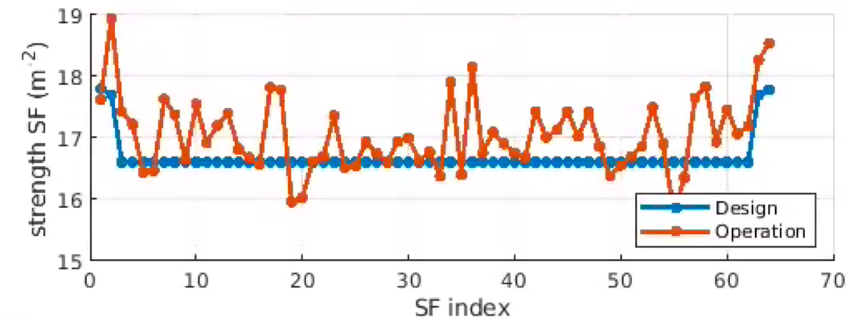
45% injection efficiency

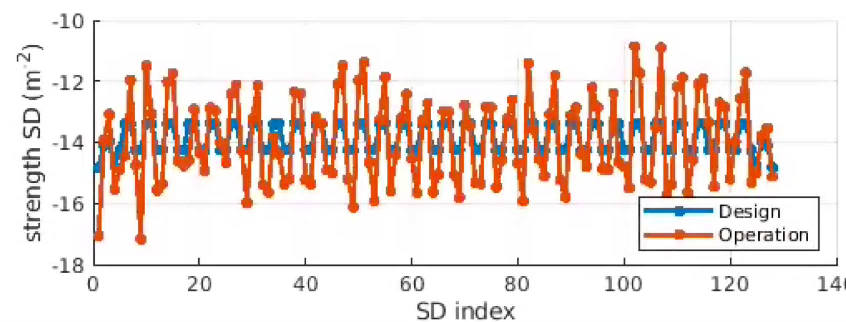
OPERATION: SINGLE MAGNET SCANS

Scanning single sextupoles or octupoles at constant vertical emittance we could increase the Touschek lifetime, exceeding the design values.









The resulting sextupole setting is not periodic, with a variation of about 10% of the design value

NONLINEAR DYNAMICS OPTIMIZATIONS: KNOB SCANS

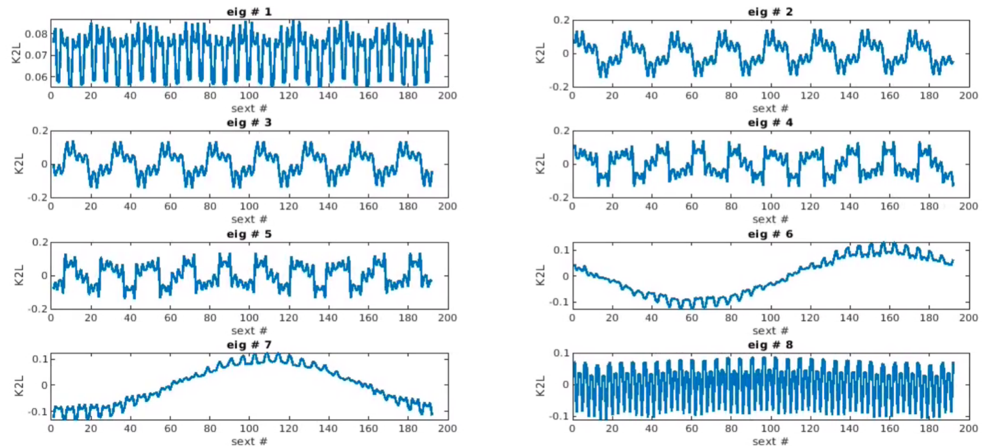
Some more effective knobs for lifetime optimizations have been studied and tested.

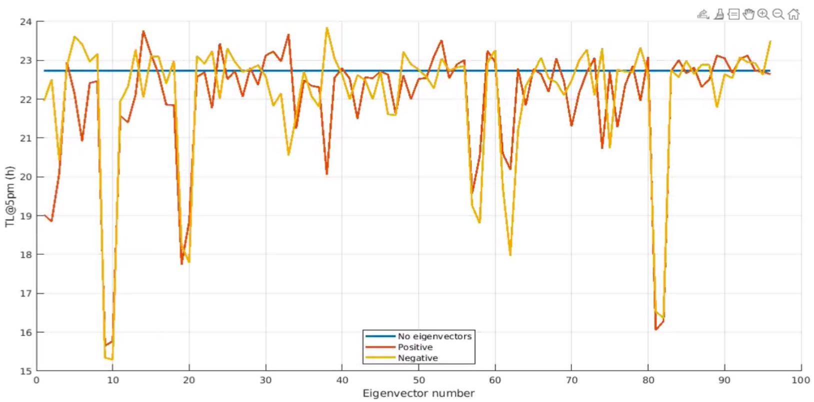
Pseudo sextupolar singular vectors for off-energy optics correction.

$$J_{quad} = \frac{\delta ORM}{\delta K_{quad}}$$

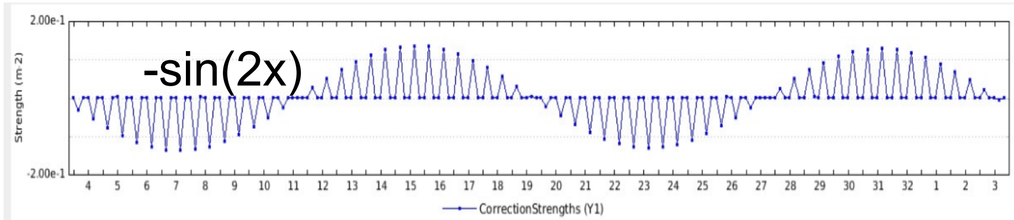
$$K_{quad} \propto 2K_{sext}\eta_h$$

$$J_{sext} = J_{quad} \cdot 2\eta_h$$





Sin/cos waves in sextupoles and octupoles



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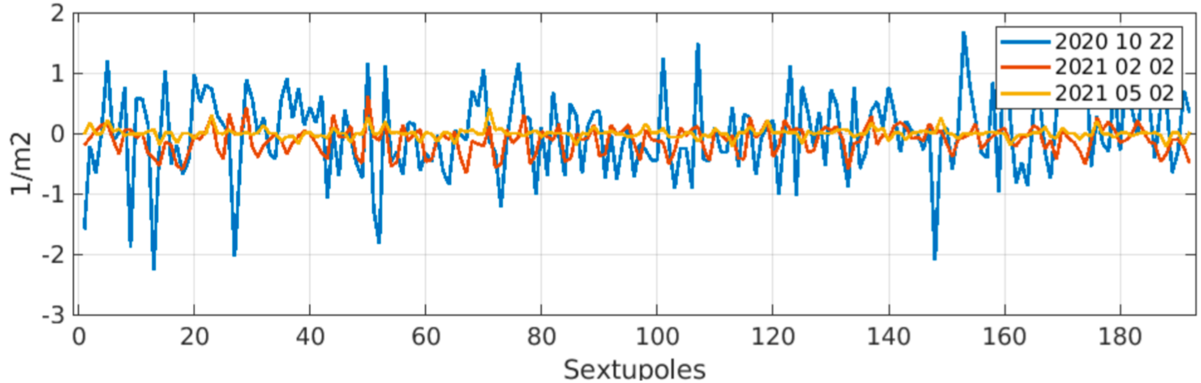
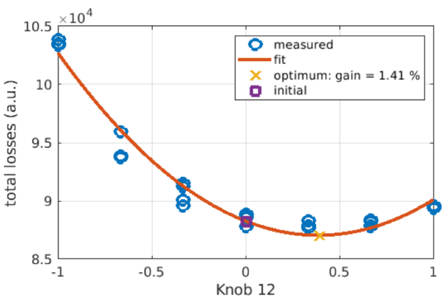
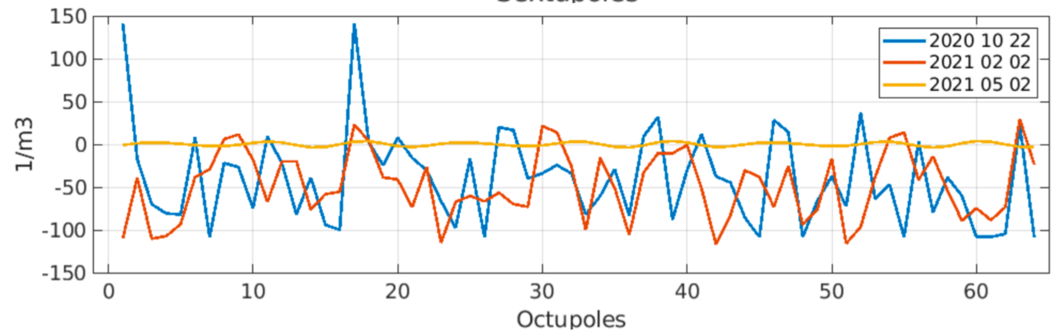
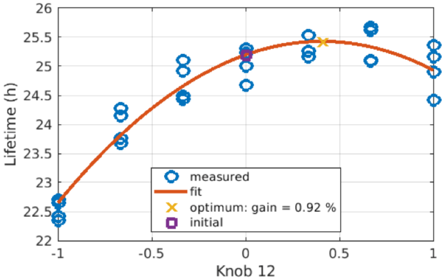
NONLINEAR DYNAMICS OPTIMIZATIONS: KNOB SCANS

A small set of sextupoles and octupoles knobs have been defined for faster lifetime optimizations.





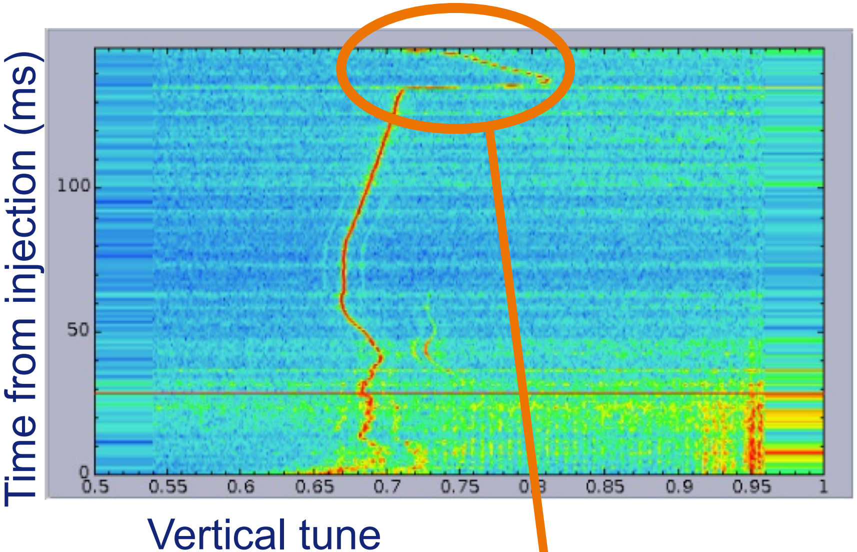




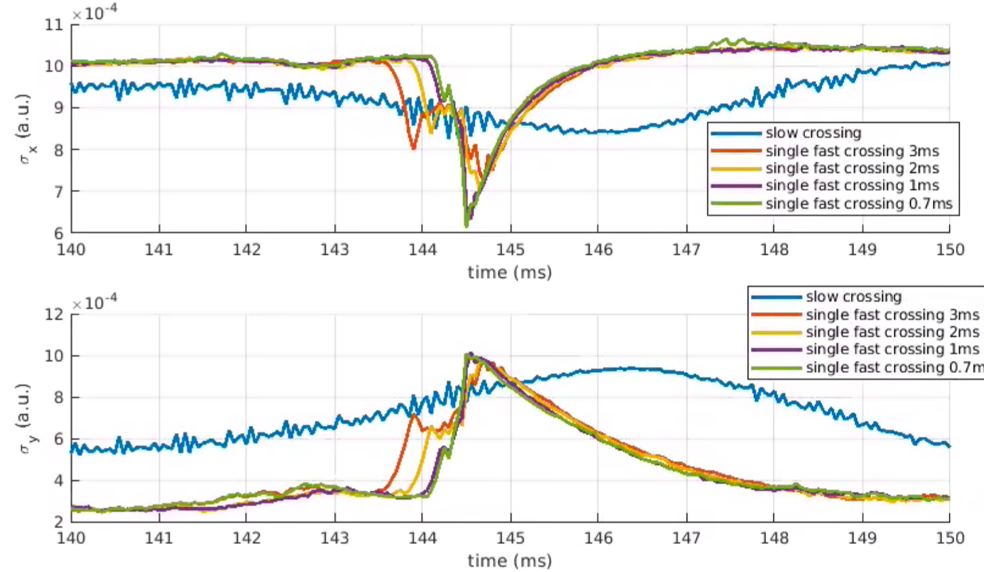
Optimization shift at each restart: about 30 knobs in 2.5 h. Final spread of correction strengths in sextupoles and octupoles is much smaller. Touschek lifetime still exceeds the design values, but the performances drift less with time.
Studies on off-energy orbit response matrix are also on-going (NOECO).

BOOSTER EMITTANCE EXCHANGE

Emittance exchange in the booster done by crossing the tunes changing the vertical quickly



The vertical tune is changed by 0.1 at extraction time



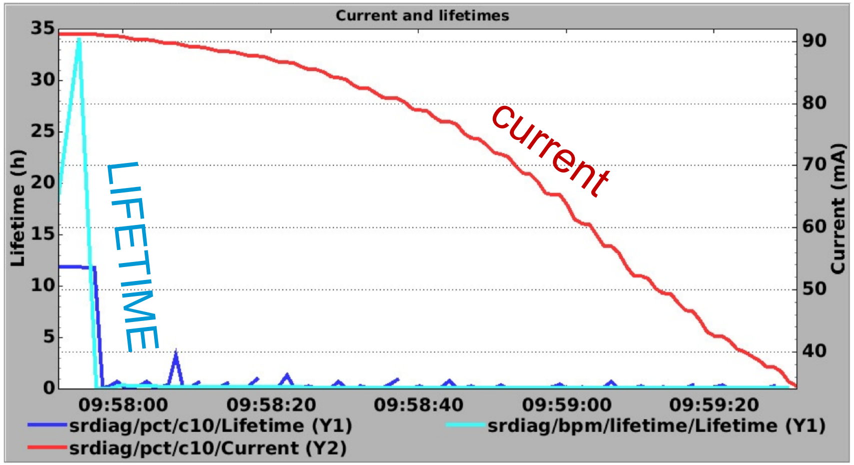
With emittance exchange in the booster, the injection efficiency improved by 5-10%

CURRENT "RAMP" DOWN: SLOW BEAM KILLER

We didn't have a way to kill the beam without stressing the RF with a quick RF off.

Several methods have been considered and used for some time:

- Kick the beam with the 4 injection kicker with one of them at a lower setting.
- Strongly blow-up the horizontal and vertical emittances and close the collimator.



Full beam kill in 2-3 minutes with most of the losses in the horizontal collimators.

CONCLUSION

- **Sextupoles optimizations with big orbit errors can help in the early commissioning phase.**
- **Calibrations of the magnets have to be checked very well! The simulator would have been a very useful tool for that.**
- **Cross talk between magnets causes a big optics mismatch and has to be studied in advance.**
- **Needed realignments of DQs can be found by analysing the eigenvectors components in the steerers. SVD truncation helps.**
- **Independent sextupole power supplies allows different kind of optimizations.**
- **Emittance exchange is good for injection efficiency.**
- **Slow beam killer is useful.**

MANY THANKS FOR YOUR ATTENTION