RCDS optimizations at ESRF

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ESLS workshop, 24-25 November, PSI, CH

RCDS ONLINE OPTIMIZER

With the robust conjugate direction search (RCDS) by Xiaobiao Huang et al, we performed all the optimization presented in the following slides directly on the storage ring.

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An algorithm for online optimization of accelerators

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ABSTRACT

A general algorithm is developed for online optimization of accelerator performance, i.e., online tuning, using the performance measure as the objective function. This method, named *robust conjugate direction search* (*RCDS*), combines the conjugate direction set approach of Powell's method with a robust line optimizer which considers the random noise in bracketing the minimum and uses parabolic fit of data points that uniformly sample the bracketed zone. It is much more robust against noise than traditional algorithms and is therefore suitable for online application. Simulation and experimental studies have been carried out to demonstrate the strength of the new algorithm.

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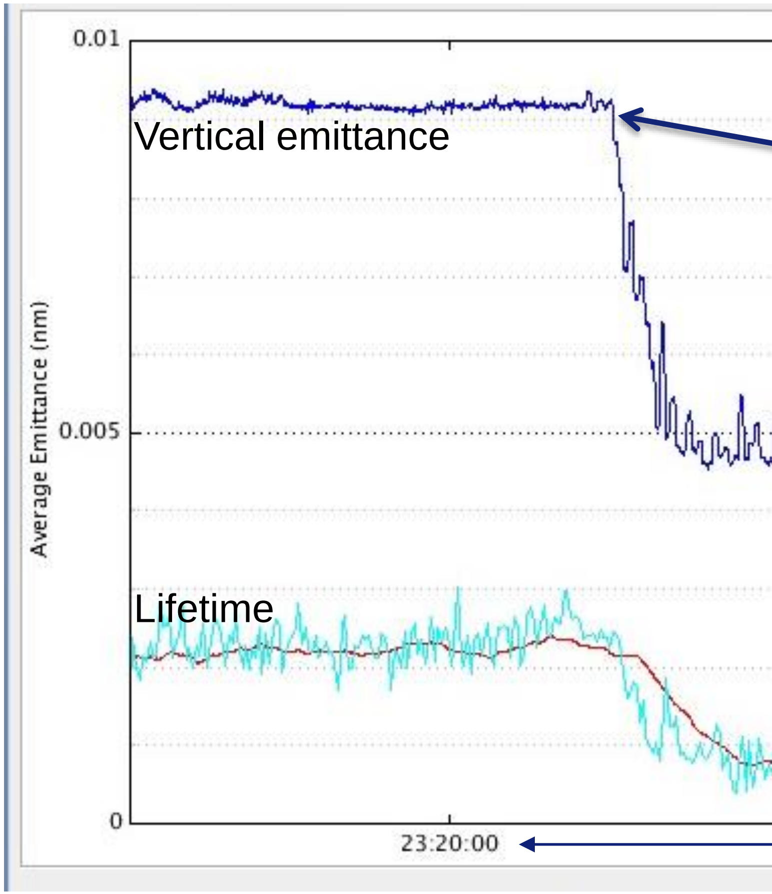
Robust Conjugate Direction Search (RCDS, X.Huang et al. *)

*X. Huang, J. Corbett, J. Safranek, J. Wu, "An algorithm for online optimization of accelerators", Nucl. Instr. Methods, A 726 (2013) 77-83.

TESTS OF RCDS ON ESRF STORAGE RING

- **Coupling 7/8, 180mA , using 64 skew quad.**
- **Optimize lifetime with 12 sextupole correctors**
- **Optimize lifetime with sextupole correctors during USM**
- **Optimize lifetime with 7 sextupole families**
- **Injection efficiency**

COUPLING (7/8 FILLING PATTERN, 180MA)



9 pm

Start the coupling optimization

4.6-5 pm

Coupling correction with 64 skew quadrupoles.

This worked out of the box, MDT shift started at 23.00!

LIFETIME OPTIMIZATION

We need to correct the lifetime measurement for:

- **Current decay**
- **Emittance variation**
- **Bunch length**

We want to optimize the **normalized lifetime**:

$$\tau_N = \tau \cdot I / I_N \cdot \sigma_{N,z} / \sigma_z \cdot \sigma_{N,y} / \sigma_y$$

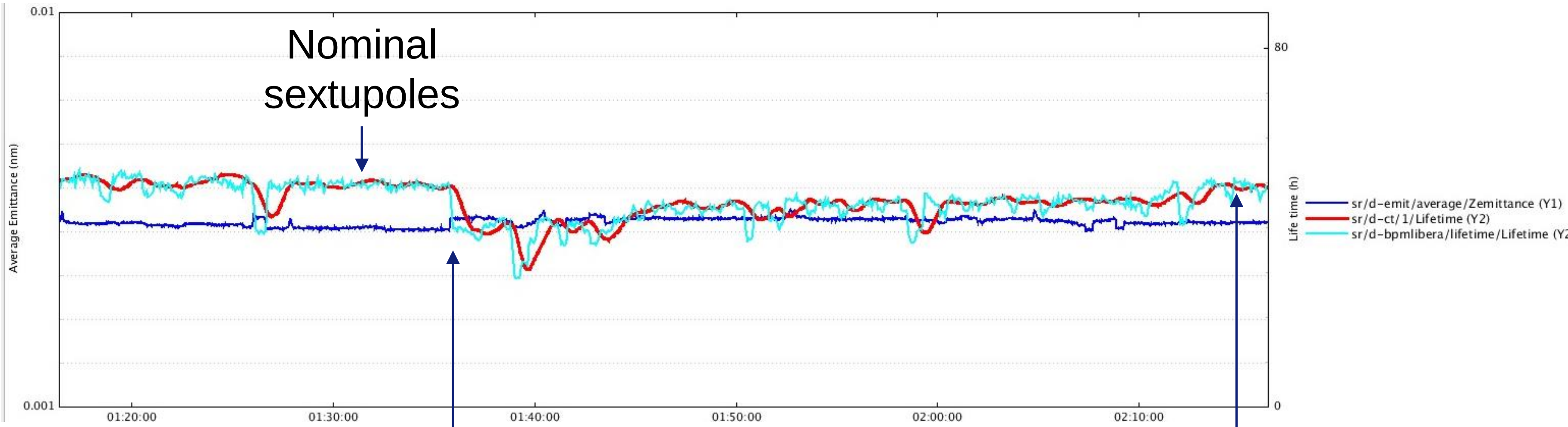
In 7/8 multibunch the lifetime is influenced by the vacuum lifetime.

$$I(t) \propto -I_N * (1/\tau_{vac} - 1/\tau) * t$$

τ_{vac}=300h (assumed, to be measured vs current)

I is the measured current

CORRECTION FROM ZERO SEXTUPOLES CORRECTORS, 5 ITERATIONS



Nominal sextupoles

Start optimization setting all sextupoles to zero current. Lifetime drops.

End of 1st iteration.

Lifetime of nominal set is recovered after 40 minutes!

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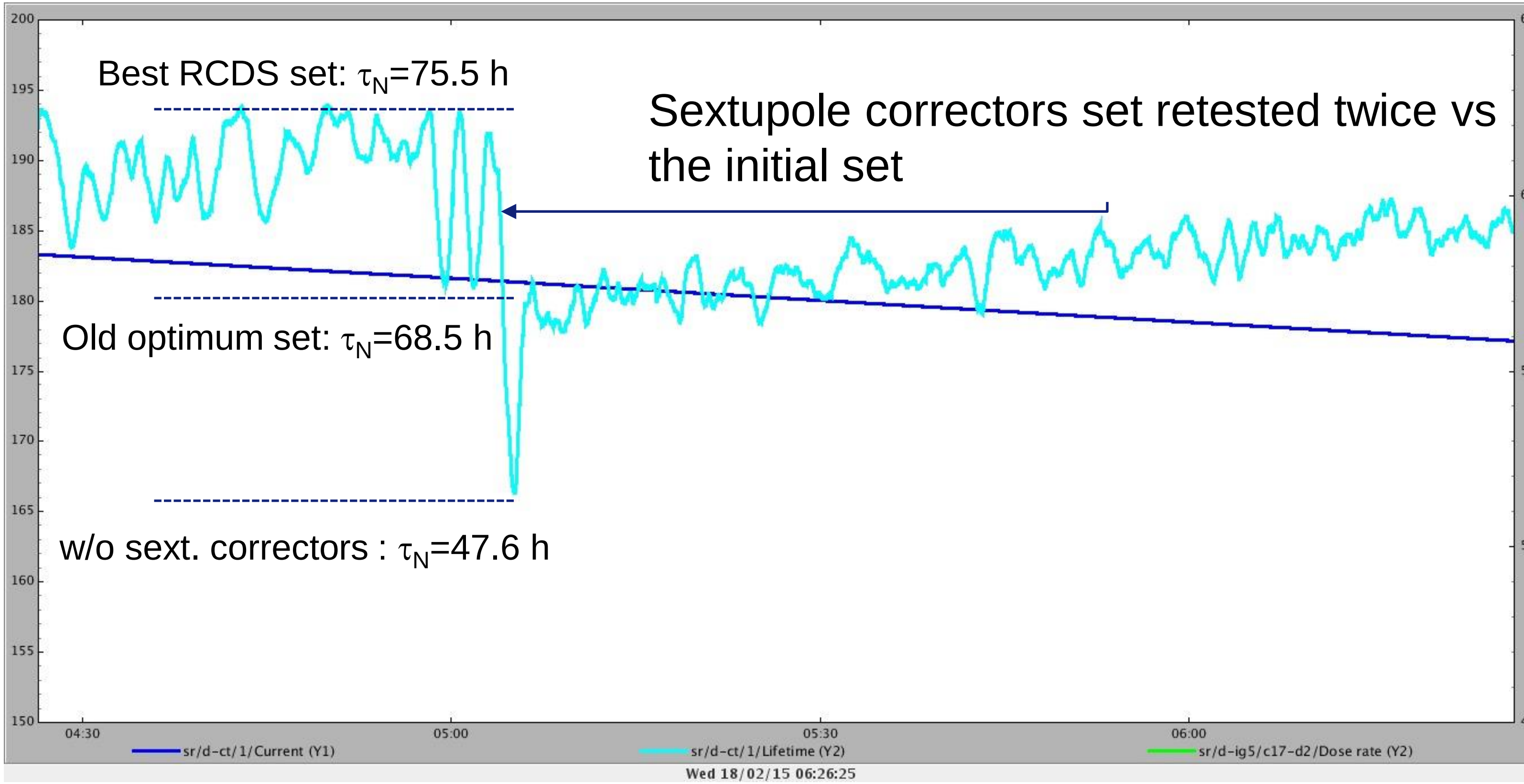
NORMALIZED LIFETIME: BEST SET IS BETTER THAN INITIAL SET



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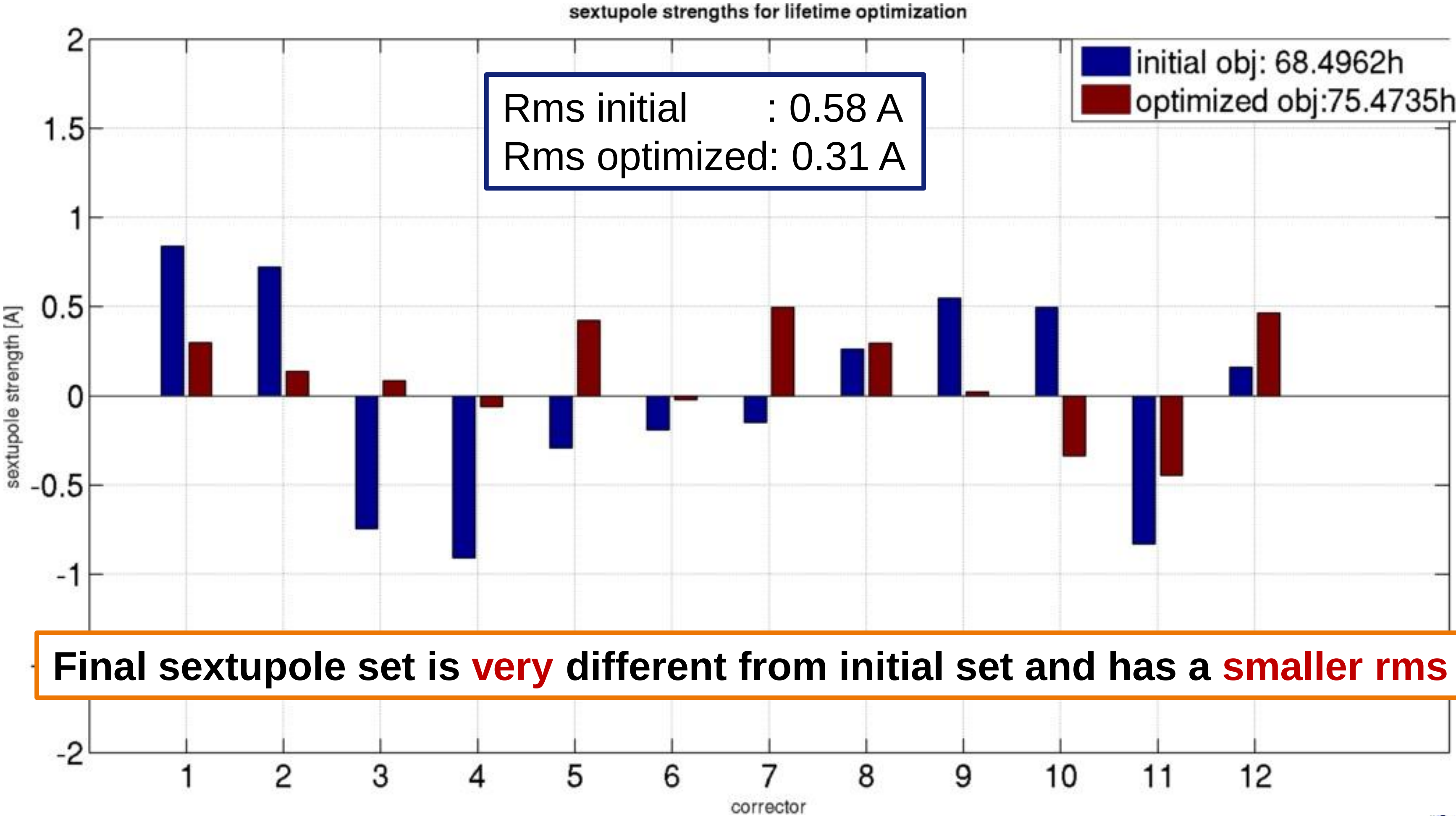
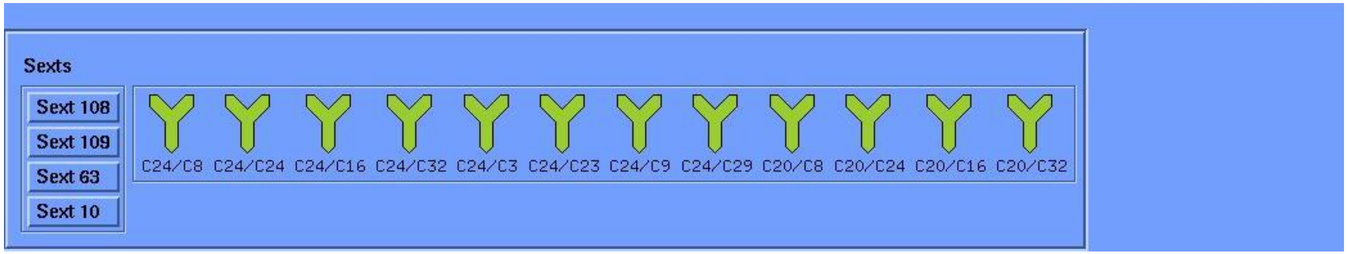
SEXTUPOLE CURRENTS



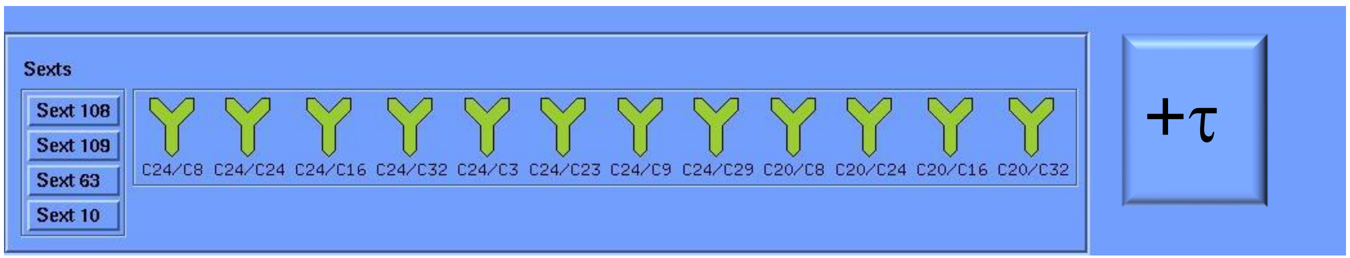
Rms initial : 0.58 A
Rms optimized: 0.31 A

Final sextupole set is very different from initial set and has a smaller rms

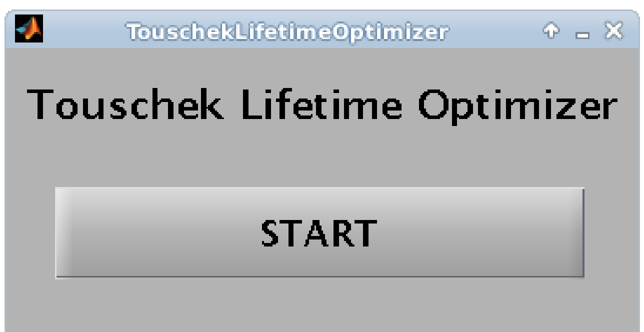
THE FUTURE?



The status: tuning of sextupolar resonances



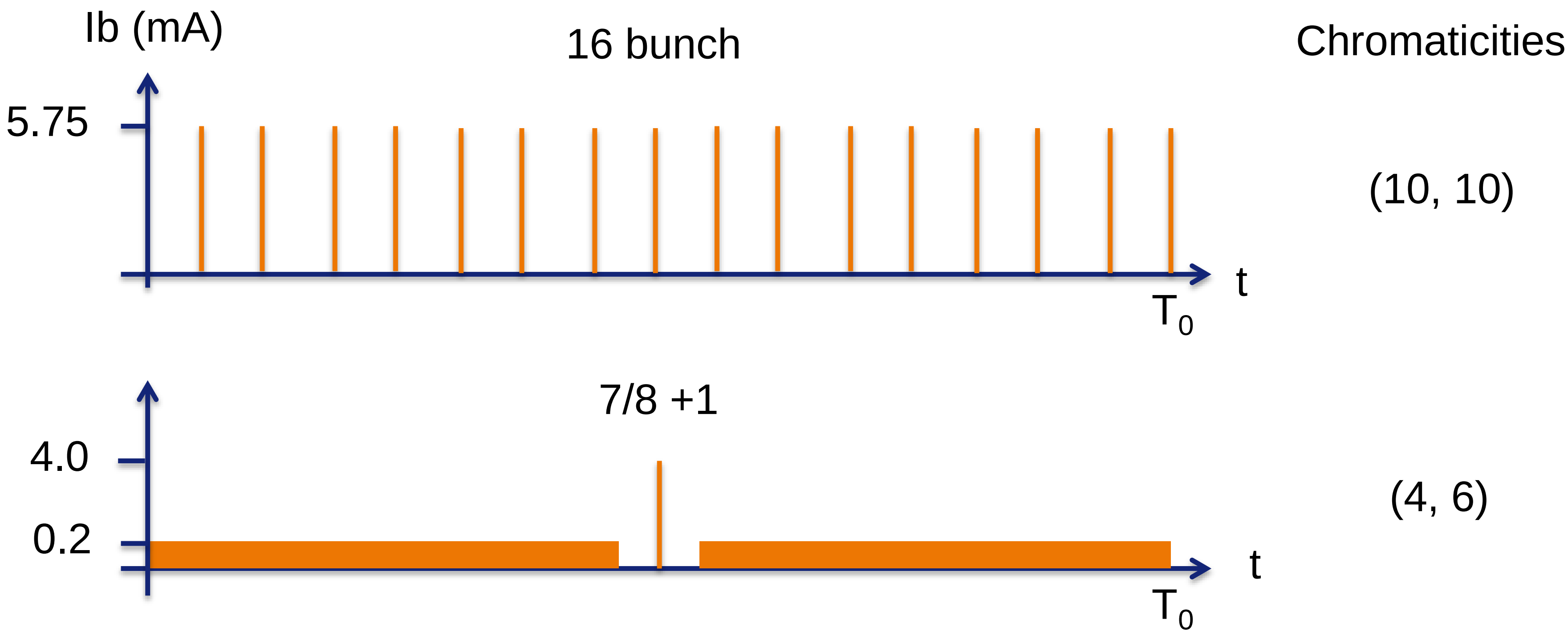
The wish: tuning lifetime



Application now available and in use in CTRM during USM

PRESENT ESRF FILLING MODES

The most used filling modes at ESRF are the 16 bunches mode (~24%) and the 7/8+1 mode (~58%).



7/8+1 multibunch | **16 bunch**

Same linear optics

Different sextupole settings

chromaticity is ~(4,6) | **chromaticity is ~(10,10)**

This difference induces cascade modification of many settings:

- **Correction files (SRCOR) due to sextupole misalignments,**
- **Sextupole correctors tuning**
- **Injection tuning, (sextupoles inside injection bump)**

Using the sextupole settings of the 16 bunch for the 7/8+1 degrades the lifetime.

OBJECTIVE

7/8+1 multibunch

16 bunch

Same linear optics

SAME sextupole settings

chromaticity is ~(10,10)

The difference is: Lifetime, degraded for 7/8+1 multibunch

Objective of the experiments has been to optimize the lifetime for chromaticity (10,10), using the Sextupole Families.

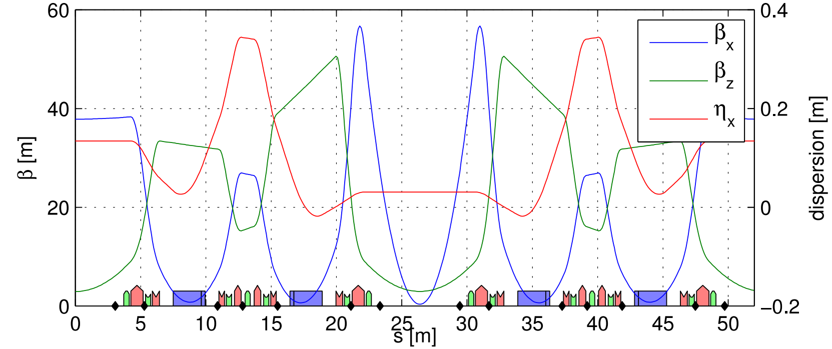
- **Better lifetime for 16 bunch mode**
- **same sextupole settings for 7/8+1 and 16 bunch:**
- **Similar lifetime 7/8+1 high chromaticity and normal 7/8**
- **More current in the single bunch**
- **No bunch by bunch feedback**

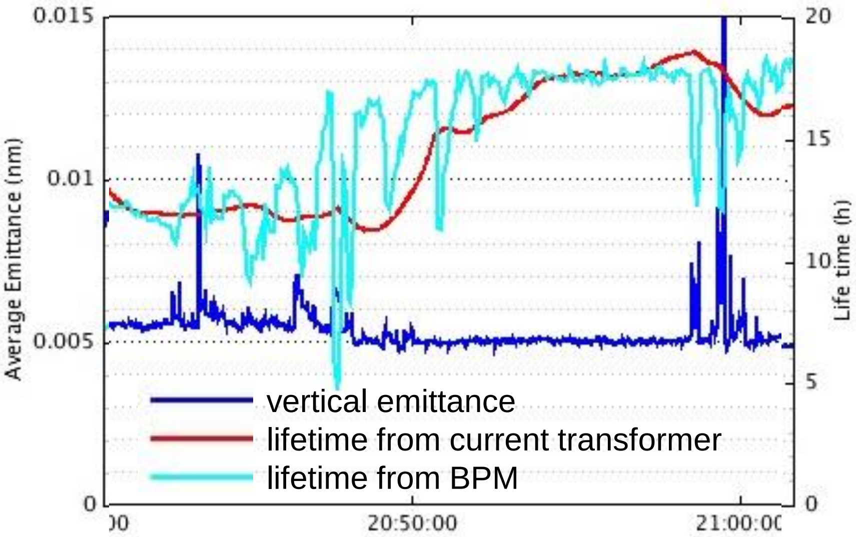
16 BUNCH MODE SEXTUPOLE FAMILIES OPTIMIZATION

We vary 5 of the 7 sextupole families and we use the last 2 to match the chromaticities.

We found a new sextupole setting with longer lifetime for the 16 bunches mode, with the same chromaticity (10, 10), necessary to store up to 8mA per bunch.

We now use this setting with users.





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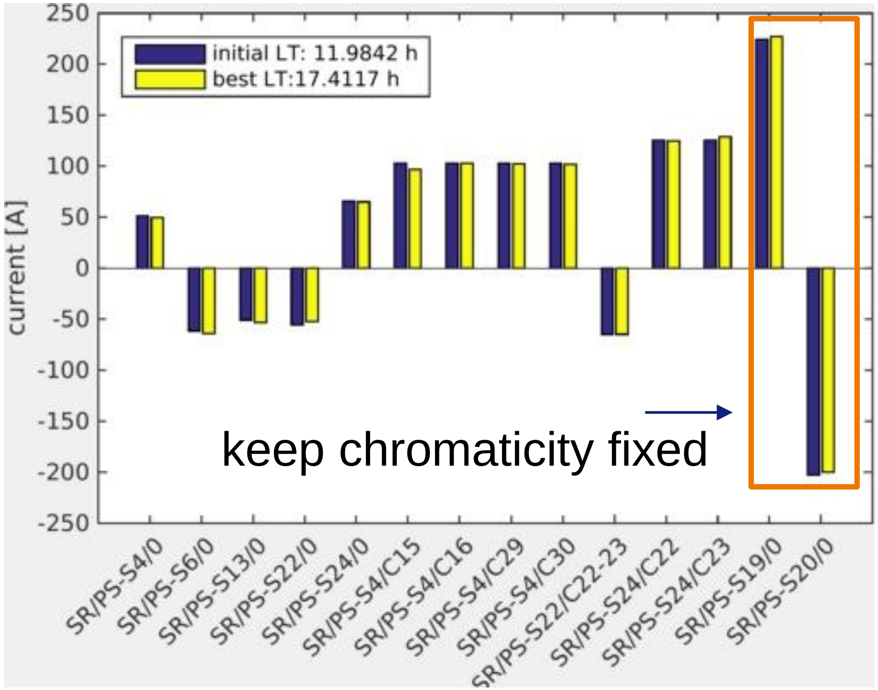
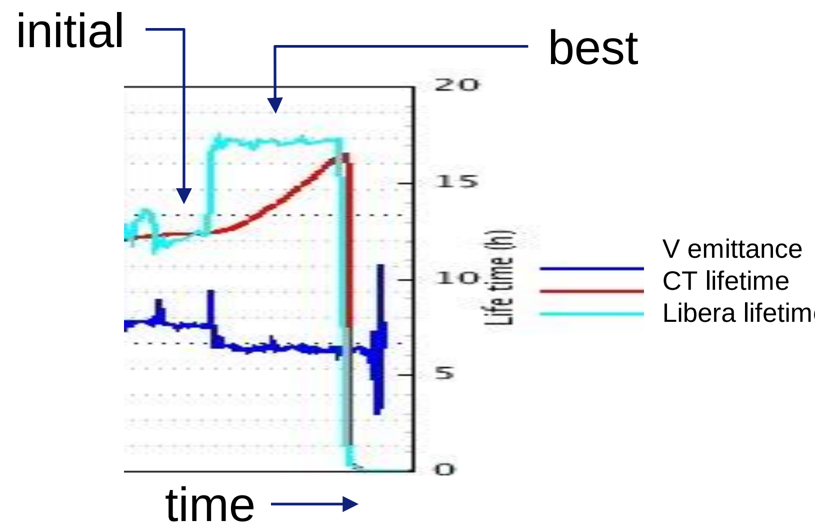
OPTIMIZATION OF LIFETIME IN 16 BUNCH

16 bunch, 23 mA, 30A range of variation of the Sextupoles, 2 iterations





+ ~45% lifetime for 16bunch

Initial chromaticity: 9.42, 9.81
Final chromaticity: 9.71, 10.85

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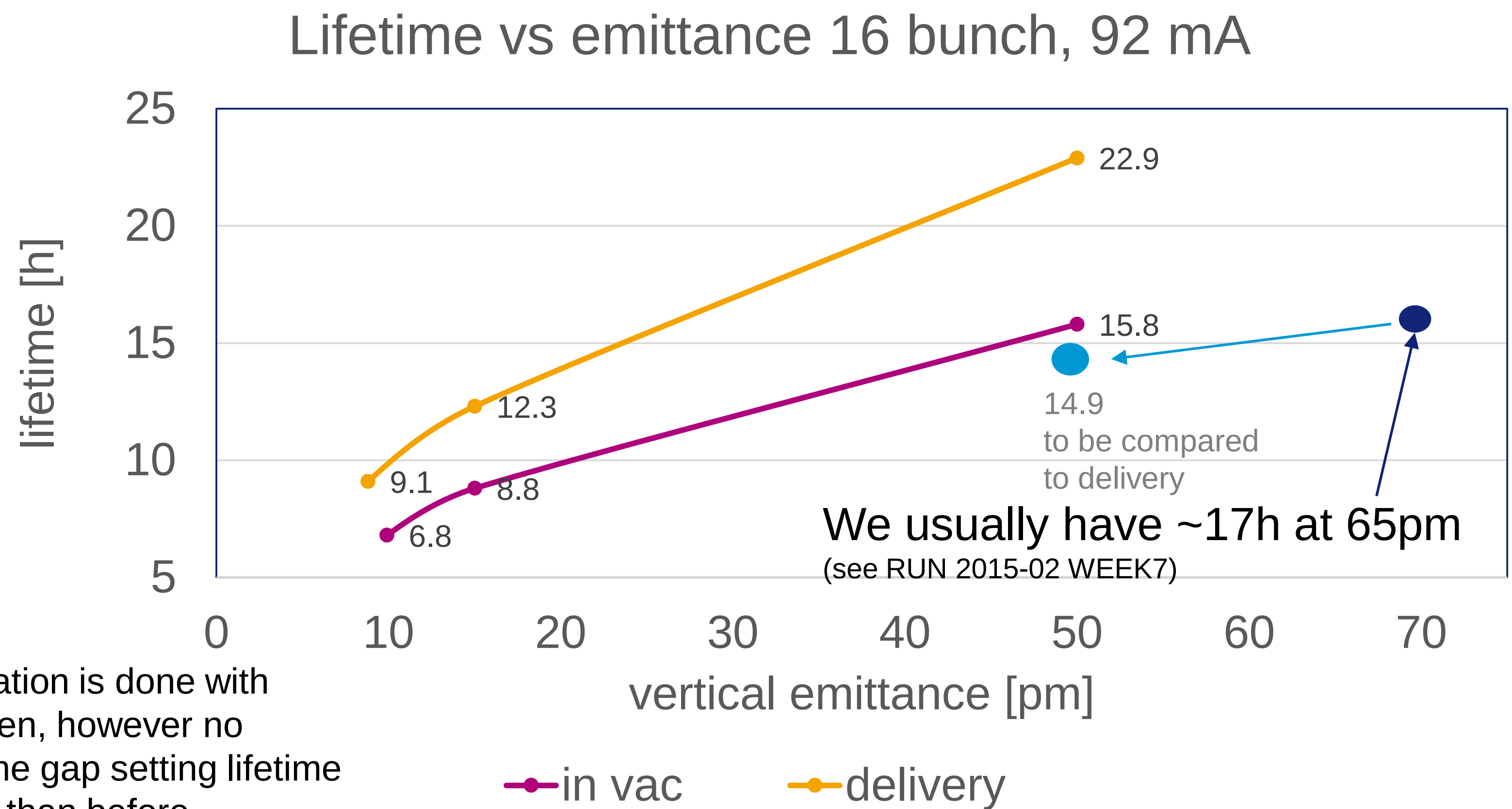
16 BUNCH WITH OPTIMIZED SEXTUPOLE FAMILY SETTING



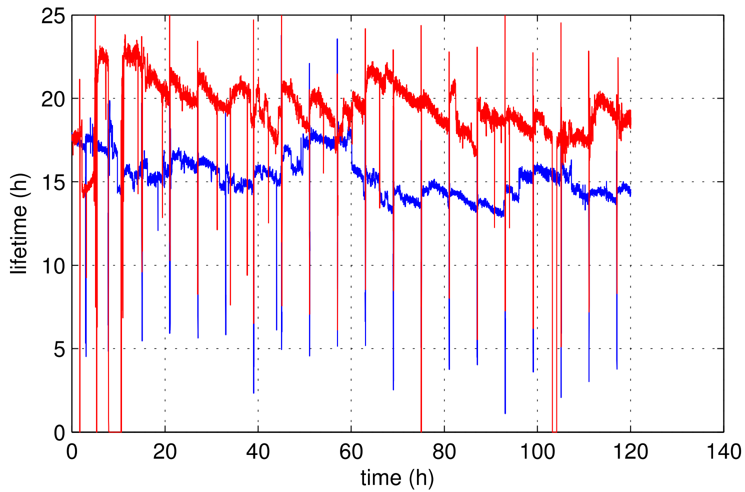
Optimization is done with gaps open, however no matter the gap setting lifetime is better than before.

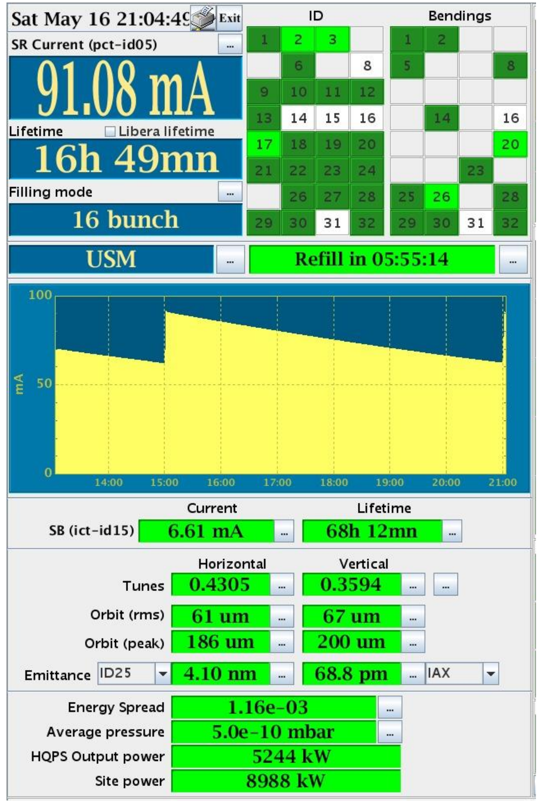
All In vacuum undulators closed to minimum

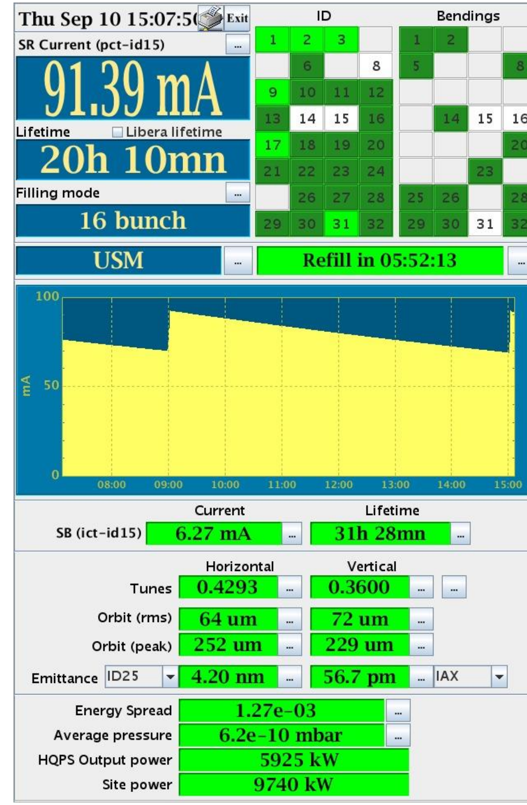
All gaps closed for beam delivery

NEW SEXTUPOLE SETTING FOR THE 16 BUNCH MODE

Lifetime of one week of operations with the old sextupole setting and with the new sextupole setting, in 16 bunch mode

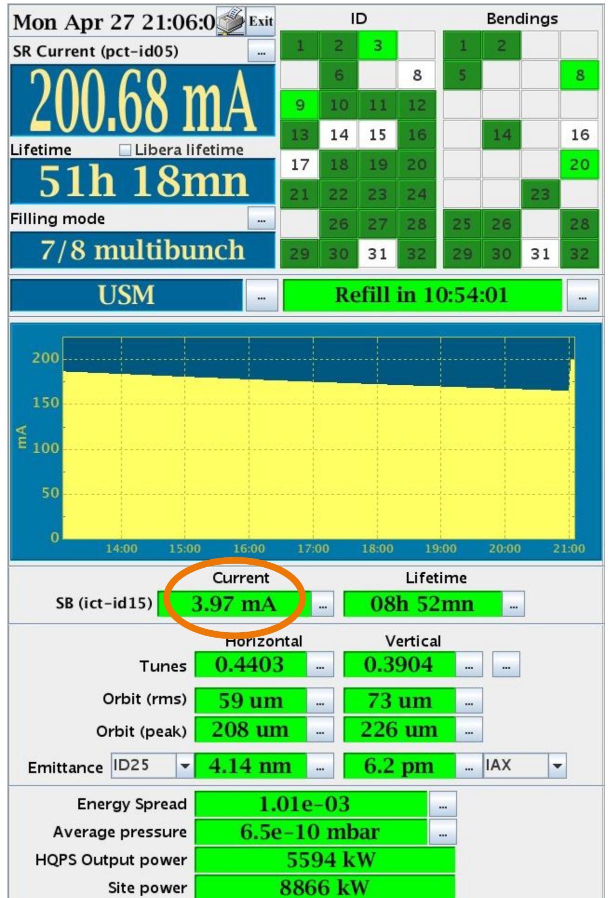


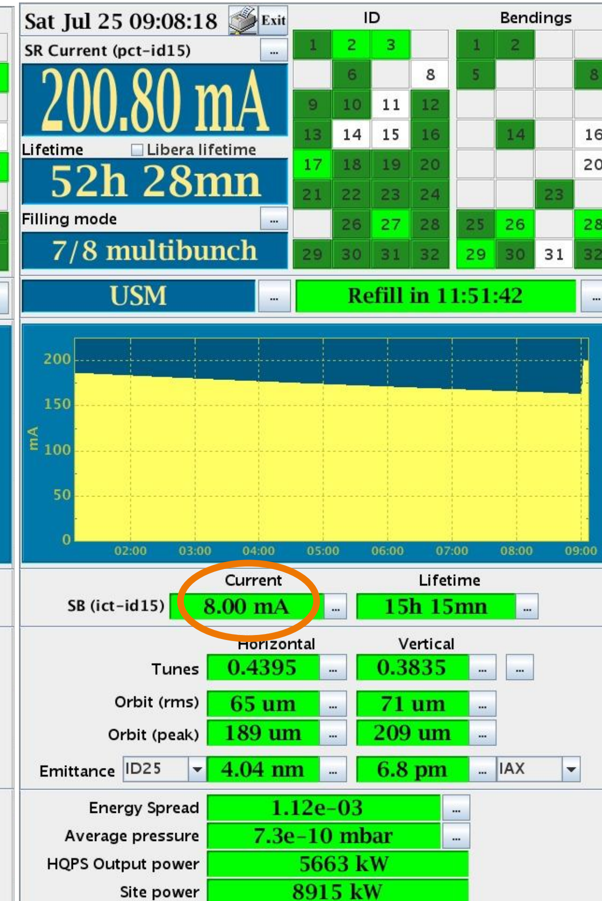




MULTI-BUNCH MODE: HIGH SINGLE BUNCH CURRENT

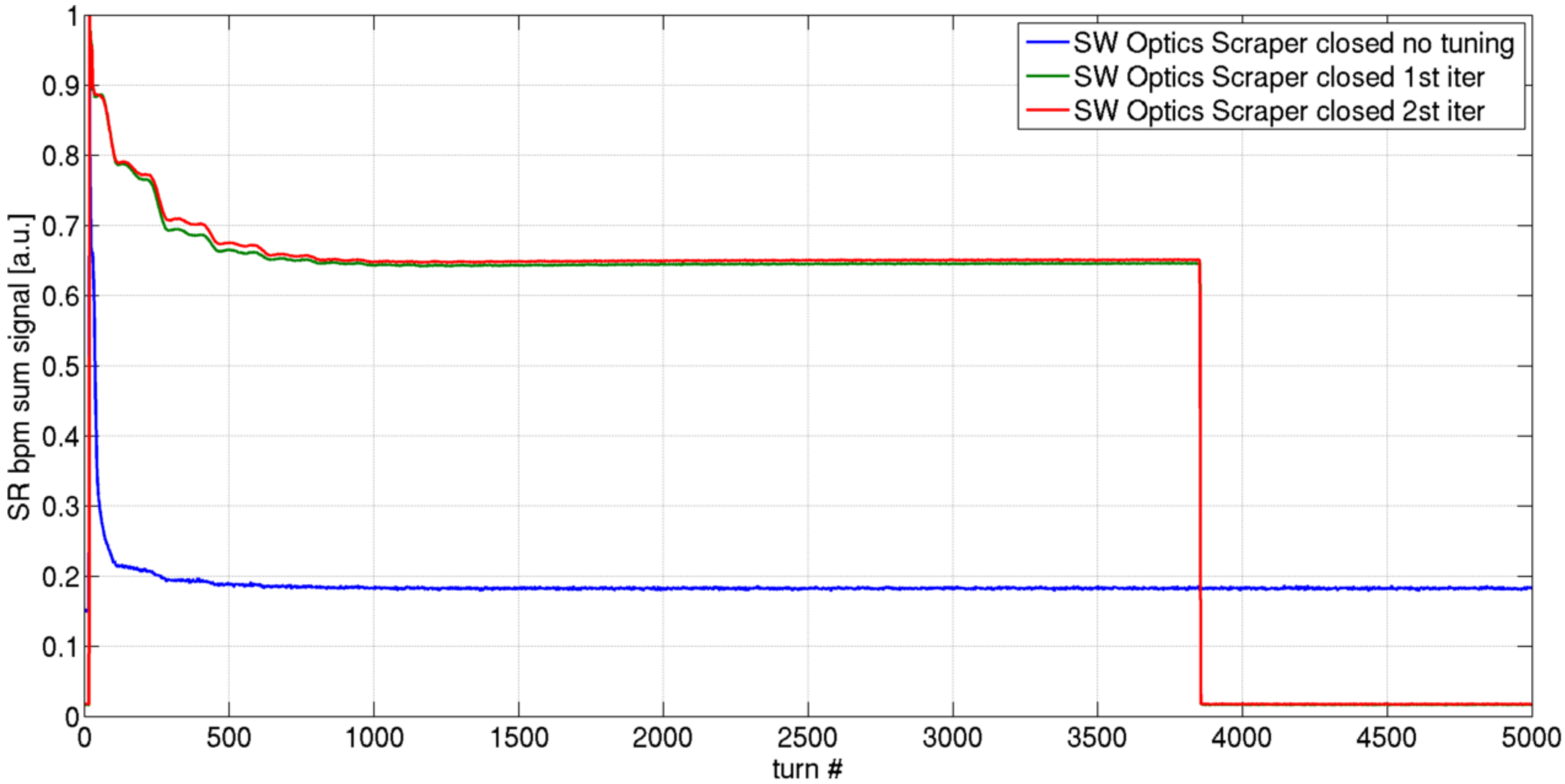
We can use the same sextupole setting also in multi-bunch mode. This allows to have higher current in the single bunch, without losing lifetime, and without bunch by bunch feedback.





Single bunch current increased from 4mA to 8mA.

INJECTION EFFICIENCY



Few iterations RCDS with H/V steerers and septas necessary
Injected beam killed after ~4k turns with delayed vertical kicker

CONCLUSION

It is possible to run the mode 7/8+8mA, with lifetimes similar to standard operations 7/8+4mA (low chromaticity)

The optics have been set in operation for Users Standard Mode.

16 bunch optics has a better lifetime compared to before.

It is possible to run in any moment the automated retuning of the sextupole correctors using RCDS (X.Huang), or tune the sextupolar resonance knobs.

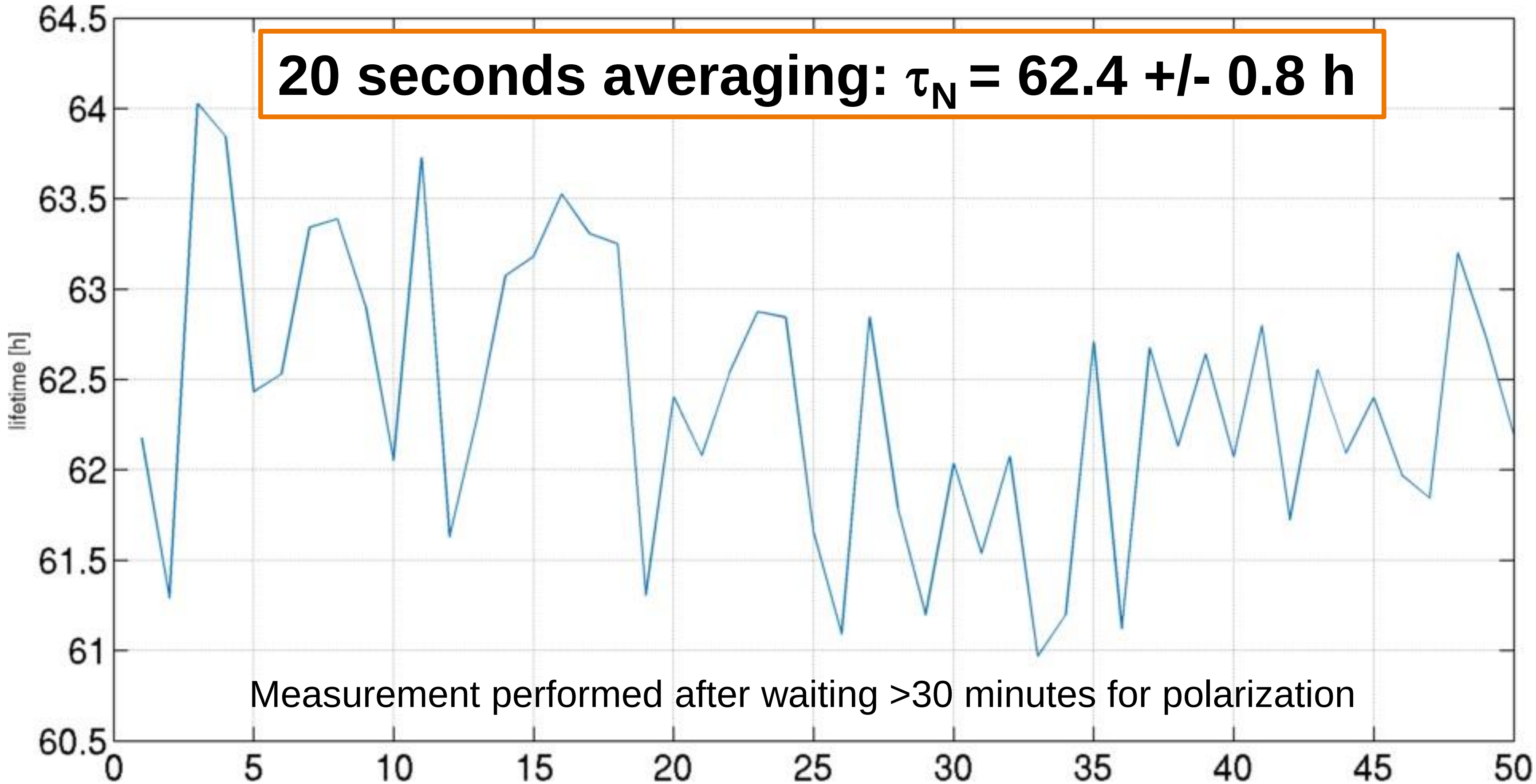
Injection efficiency tuned using RCDS.

More iterations (usually 2-5 used above) could be beneficial, but would take a very long time.

MANY THANKS FOR YOUR ATTENTION

BACKUP

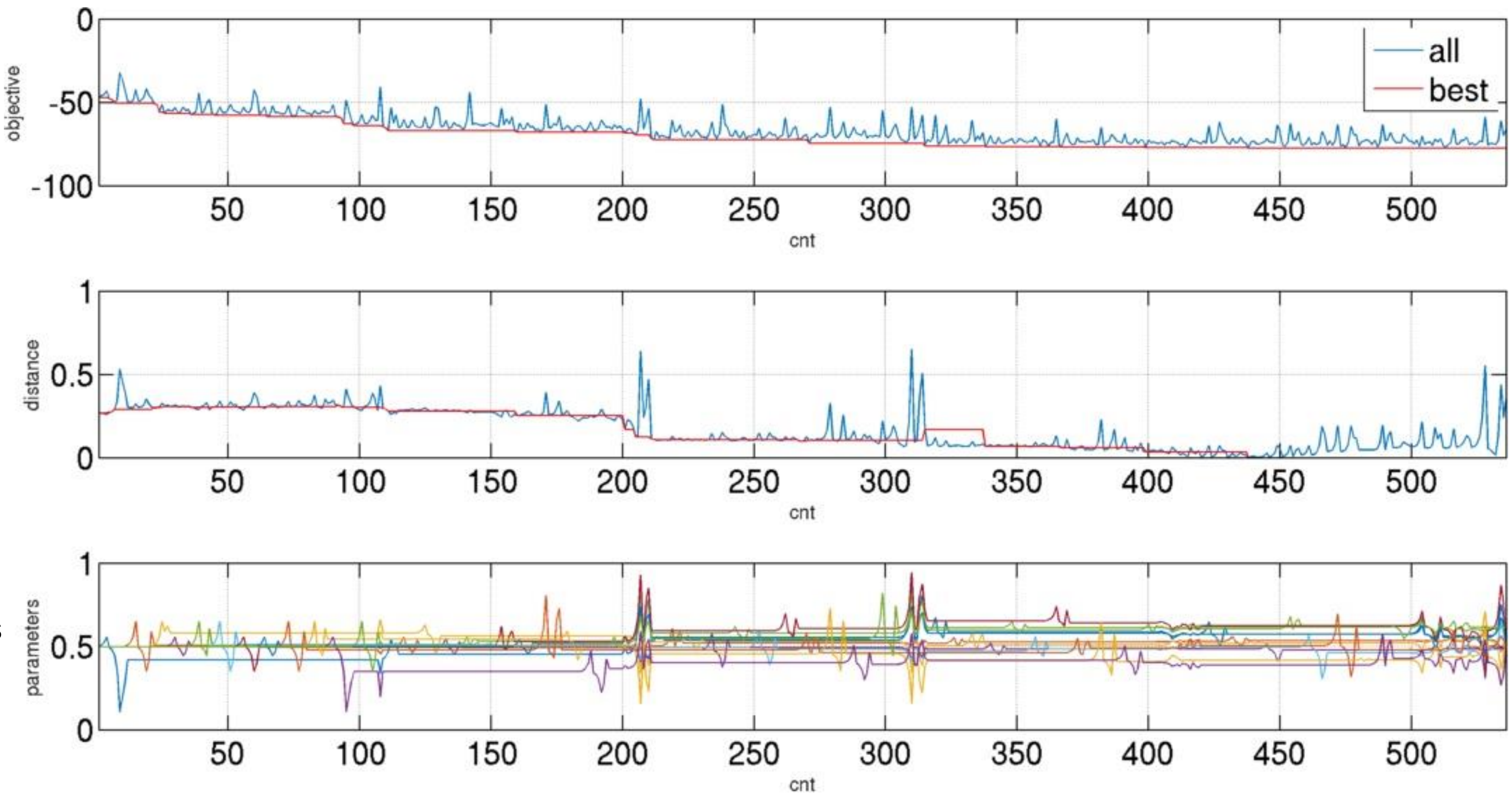
NORMALIZED LIFETIME NOISE EVALUATION



50 samples every 20 seconds

5 ITERATIONS OF OPTIMIZATION ~4H

$-\tau_N$



12 sextupole correctors currents ([0,1] = [-2A, 2A])

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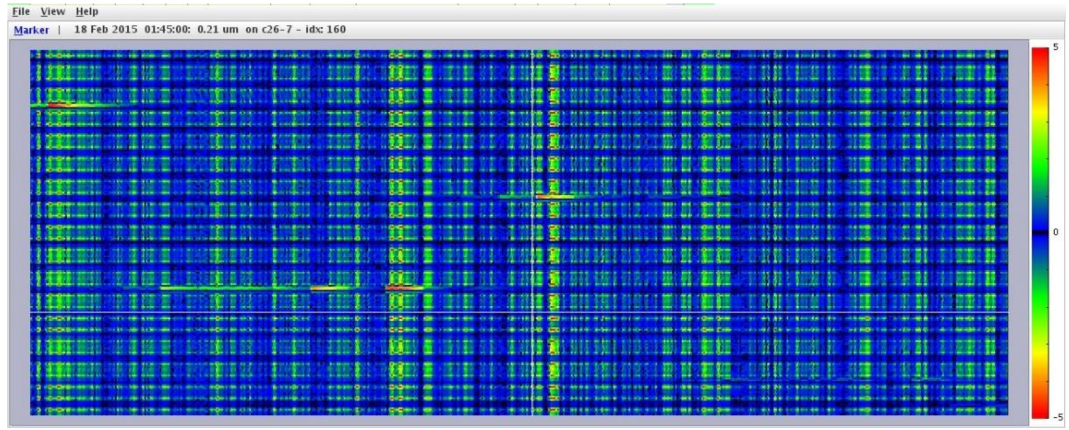
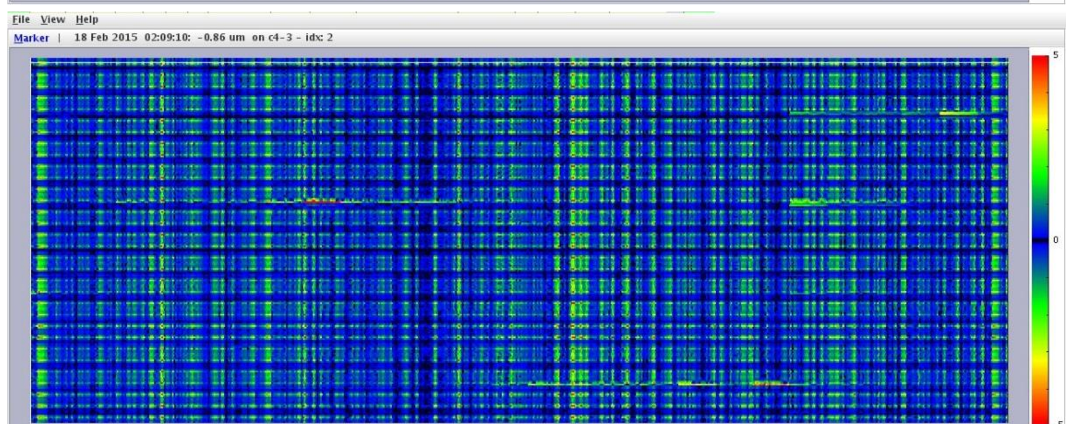
SEXTUPOLE CORRECTORS IMPACT ON ORBIT (WITH FOFB)

Sextupole correctors introduce some orbit that is observable in the FOFB tapis-roulant.

1st iteration, each sextupole is moved independently



After 1st iteration, sextupoles are moved along optimal directions



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OTHER TESTS

Cleaning worked in 7/8 and 16 bunch. No problems and no retuning.

E.Plouviez suggested to inject 4x8 mA (chromaticity) and try to use the bunch by bunch feedback to stabilize 10mA/bunch. Work still to be done. Lifetime 9h, emittance (5nm,9pm), 33mA.

E.Plouviez suggested to inject Uniform 203mA

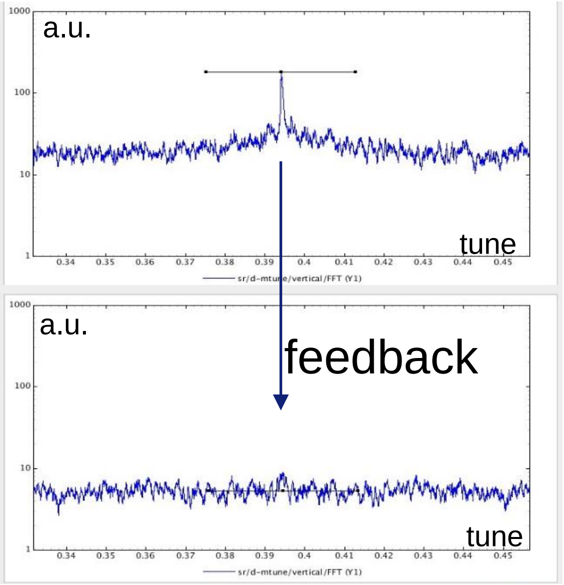
to see the effect of chromaticity on the

ion instability. Lifetime: 50h

The vertical emittance without feedback: 8.4 pm

The vertical emittance with feedback: 7.9 pm

Feedback is working ok but not so effective.

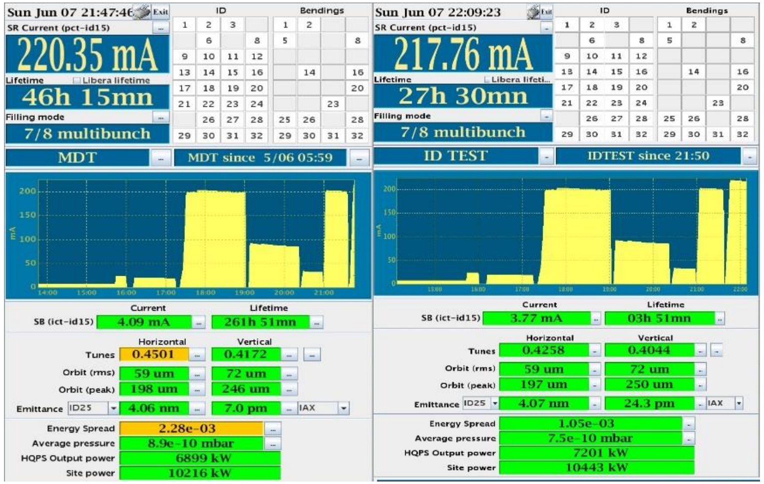


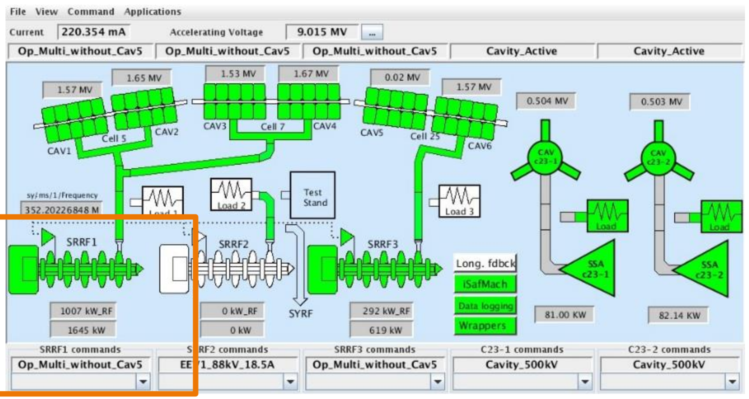
+10% CURRENT TEST

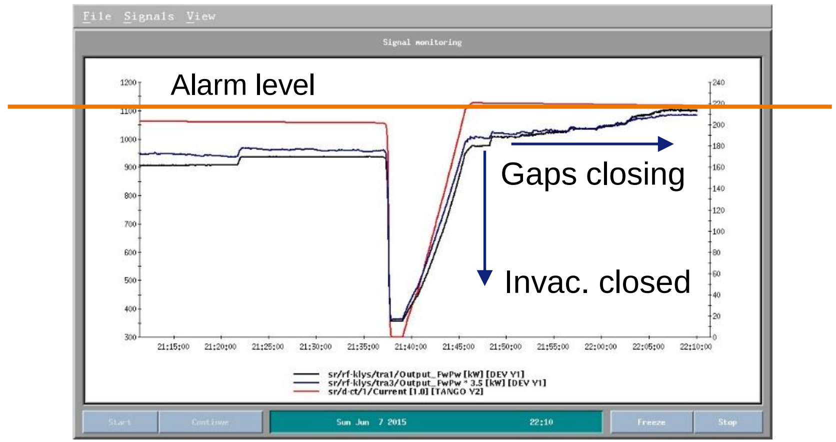
To ensure the radiation safety margin we test the stability of the optics at 216+4mA (+10%).

We close all invacuum undulators and then all gaps until power density limit is achieved. We are stopped in this operation by an alarm on TRA1.

Only 4 ID still to be closed.







We consider the test PASSED.

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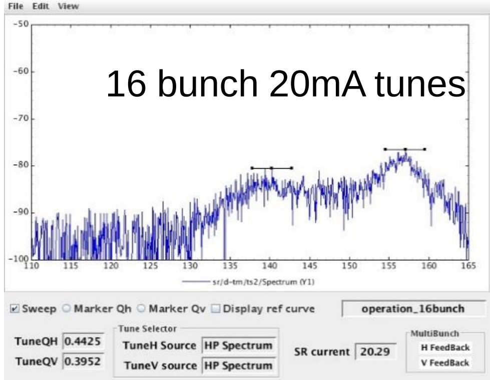
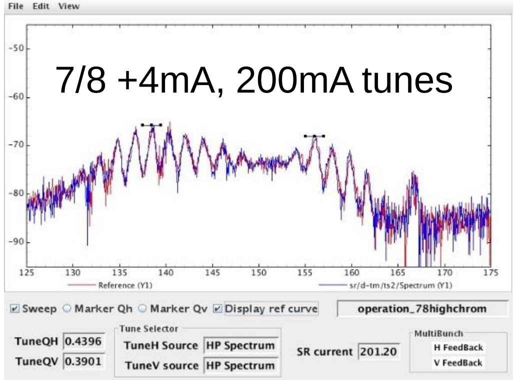
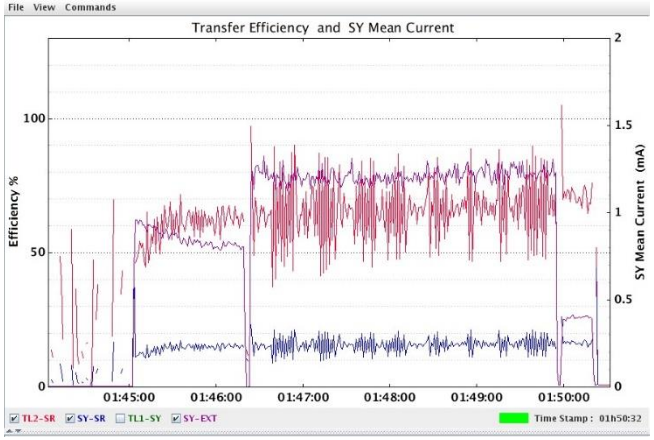
TUNES

Tunes not so easy to find





Injection efficiency poor, but comparable to 7/8+4mA at nominal chromaticity.



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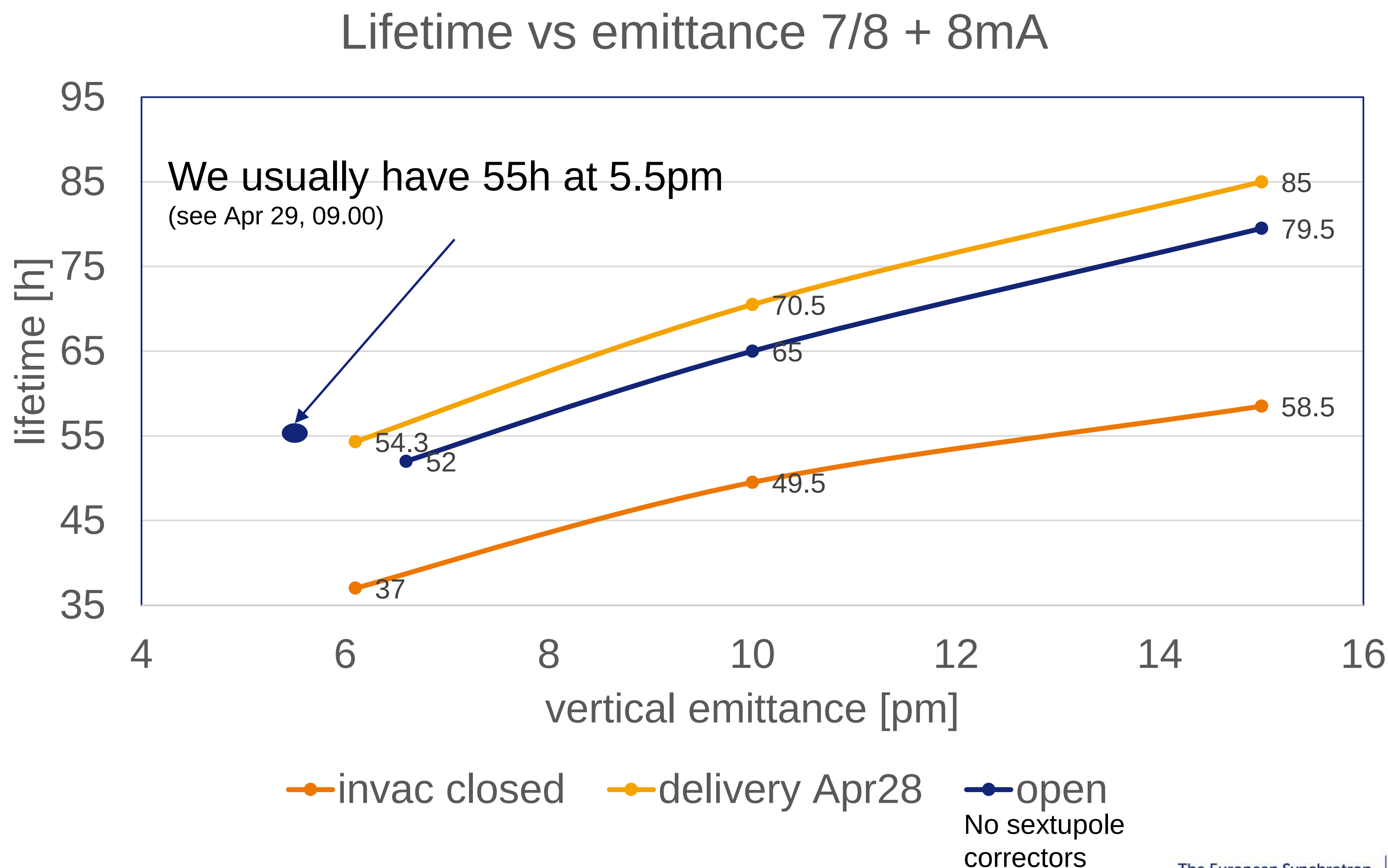
7/8+1 WITH HIGH CHROMATICITY OPTICS



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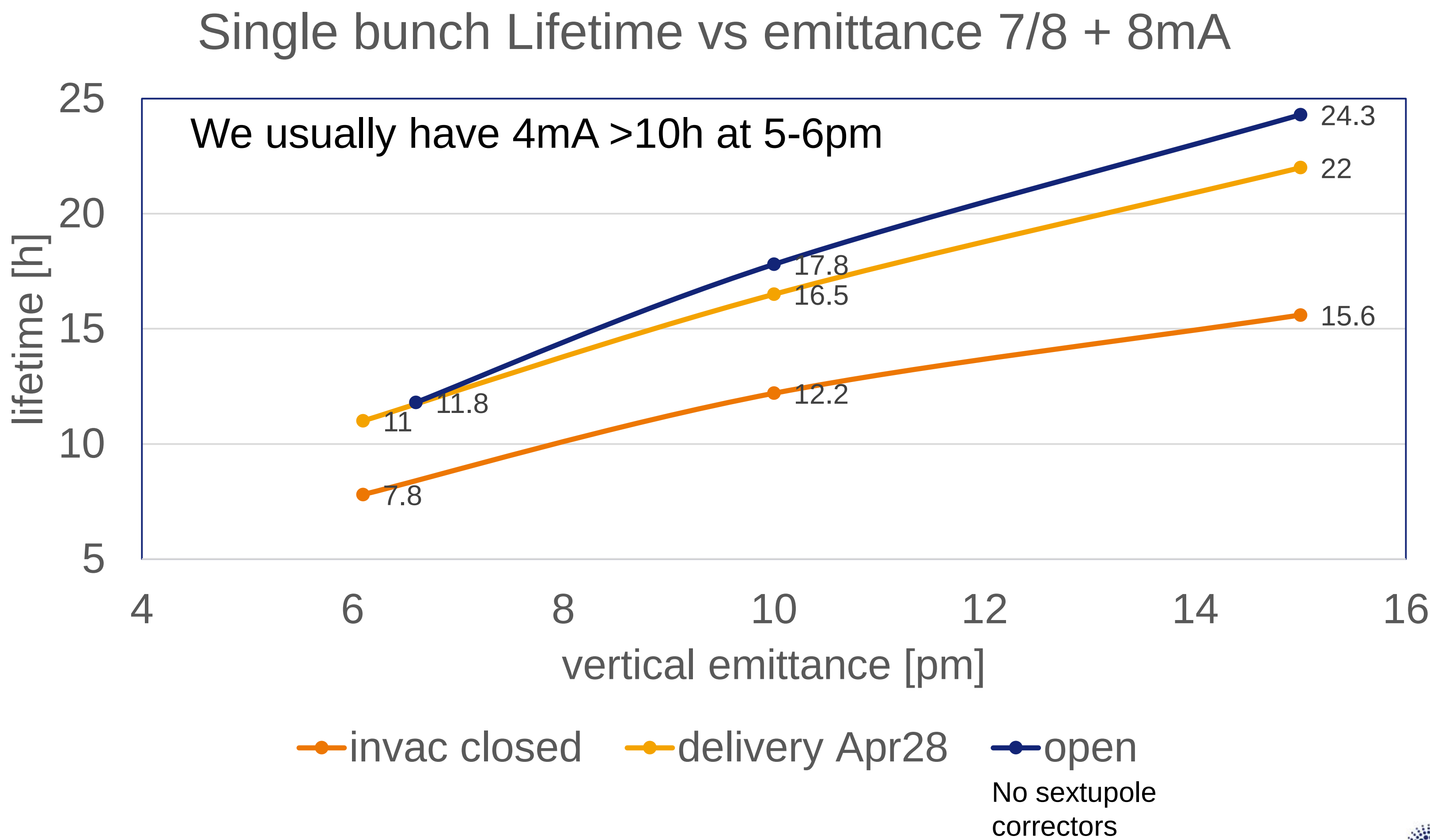
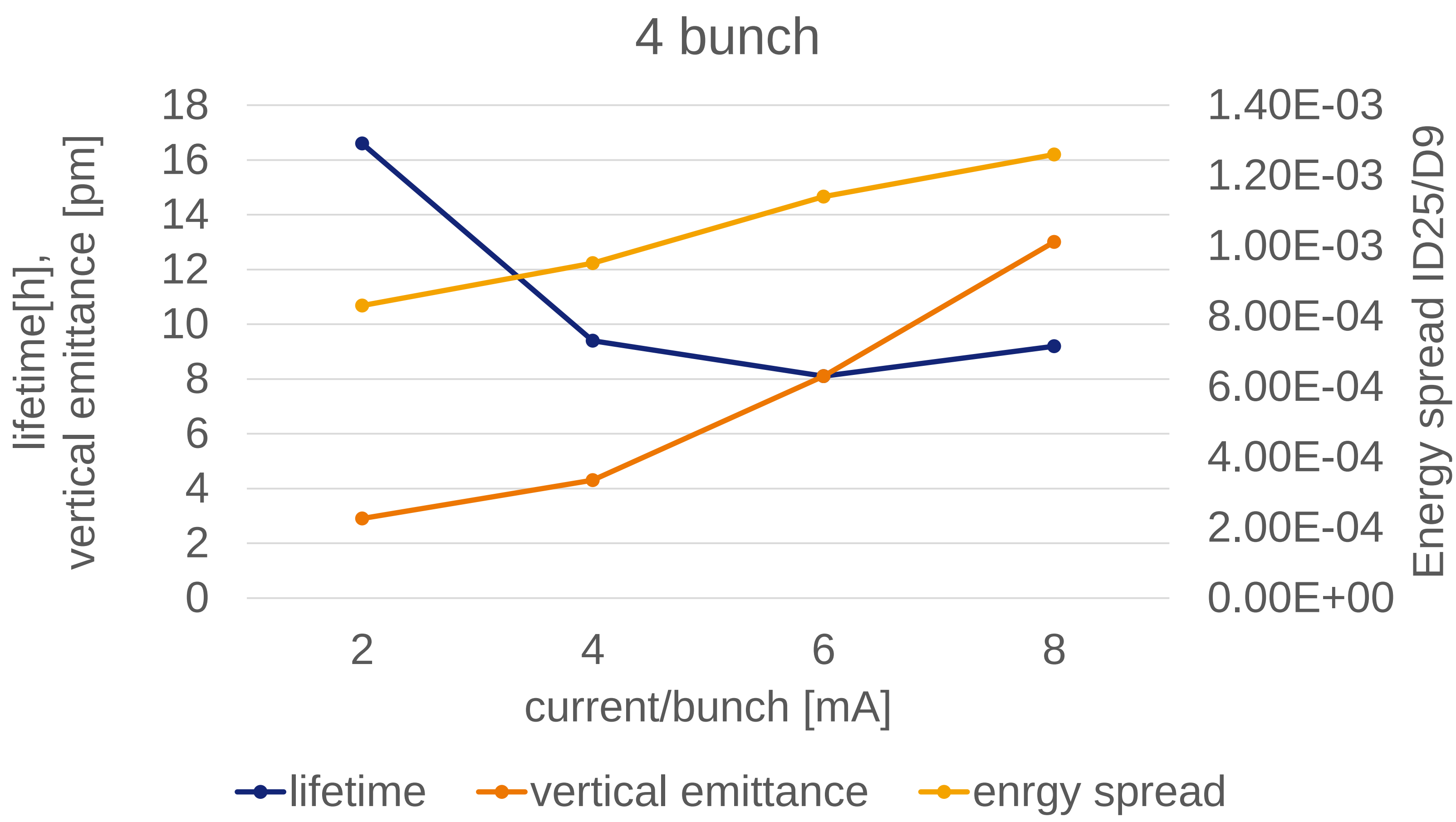
SINGLE BUNCH OF 8MA



SINGLE BUNCH PROPERTIES



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