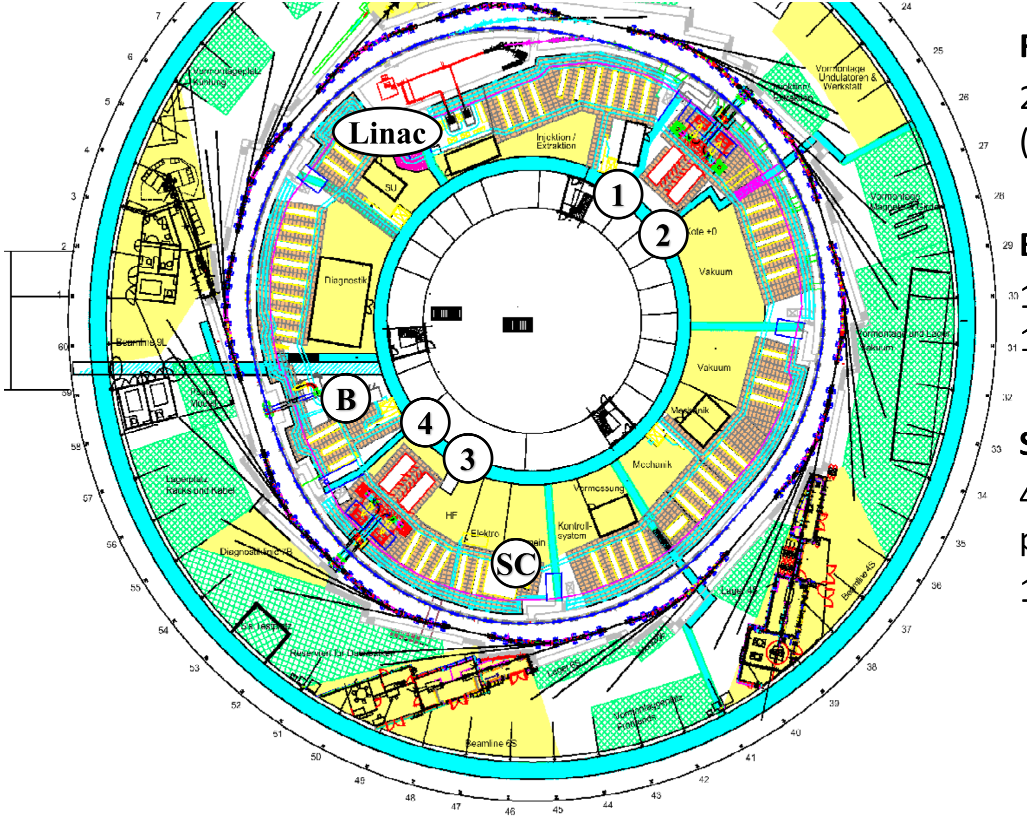
Lukas STINGELIN :: RF Systems 1 :: Paul Scherrer Institute

Simulations of Robinson Instability for SLS and SLS 2.0 with ELEGANT

Preliminary Results for multilateral discussion, ESRF, HZB, KEK, SOLEIL and PSI

23th of June 2021

Layout of the SLS RF-Systems



Full Linac (100MeV):

2 pulsed klystrons
(35 MW)

Booster + Teststand RF

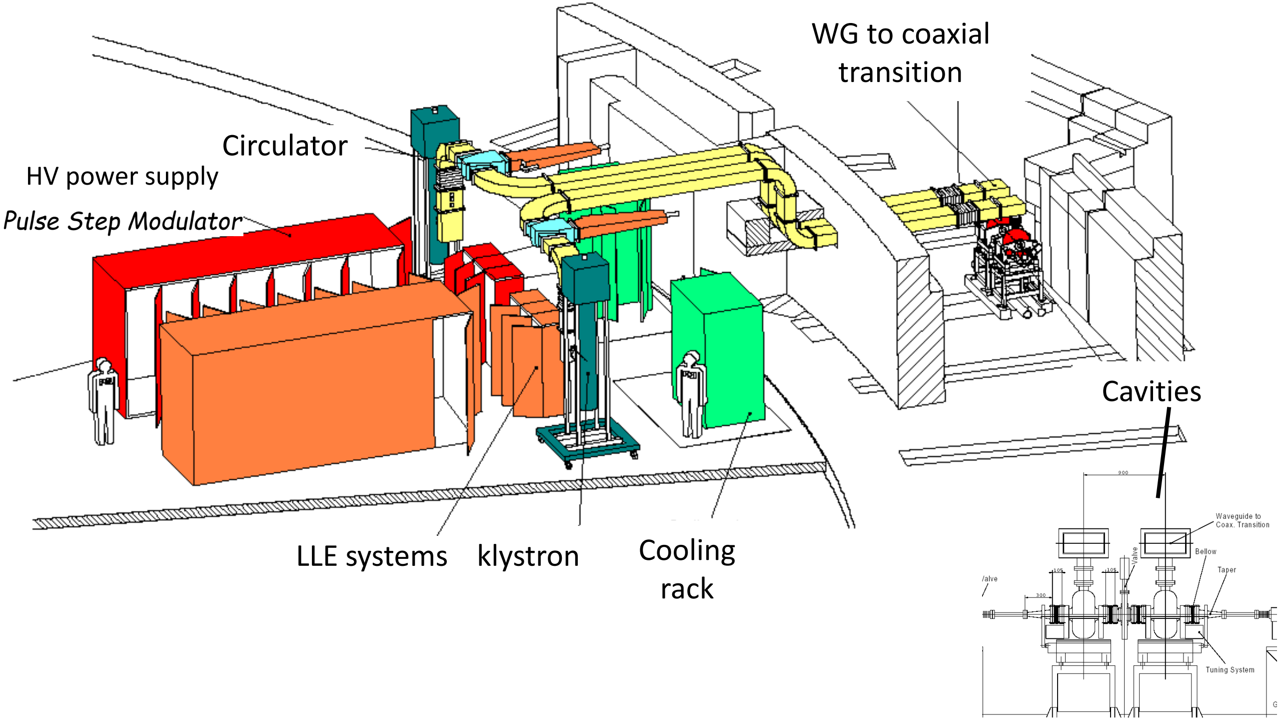
1 Klystron plant 180 kW
1 Solid state plant 60kW

Storage ring RF

4 independent Klystron plants 180 kW 500MHz

1 Super-3HC 1.5GHz

Facility overview: Klystron RF plants



SLS 3rd harmonic Super Conducting system

↳ Use of an idle (only beam-powered) super-conducting cavity

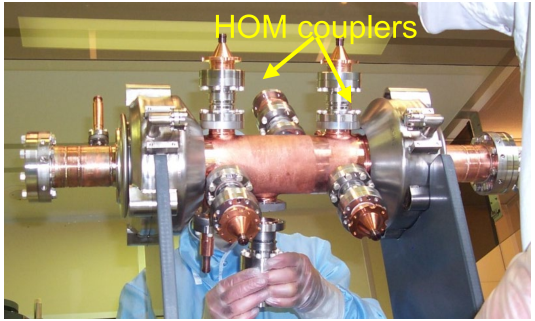
↳ “Scaling” of the 350 MHz sc cavity developed at Saclay for SOLEIL

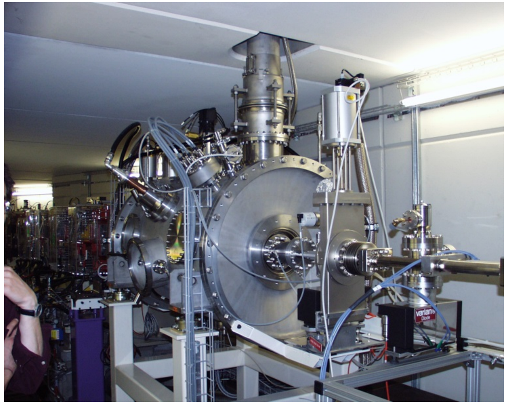
↳ 2 Nb/Cu cells (4.5 K)

↳ 6 coaxial HOM couplers

(2 longitudinal and 4 transverse)

↳ production of 2 cryo-modules (1 for SLS, 1 for ELETTRA)





Nominal voltage <800 kV (4MV/m)

Tested up to 11 MV/m

R/Q=88.4 Ohms (Q= 2 10^8)

Kryo power needed at 4.5 K and 4MV/m: 45.3 W (~33W Ohmic!)

Total GHe flow:

1.171 g/s = 5.2 l/h of liquefaction

SUPER-3HC collaboration:CEA-Saclay, PSI, Sincrotrone Trieste and CERN

SLS OPERATION WITH 3rd HARMONIC

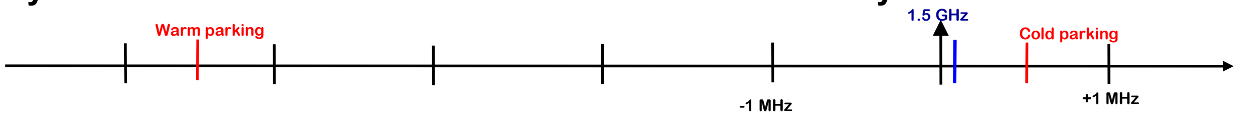
WARM OPERATION (cavity cooling with air or Ghe).

With parked cavity, stable operation up to 200 mA.

At higher current overheating of the cavity and excitation of the long. Coupled Bunch Modes (CBM):

- generated probably by an High Order Mode of the normal conducting cavity system.

- generated by the fundamental mode of the warm 3rd harmonic cavity?



COLD OPERATION (4.5K)

- **With *parked cavity*, stable operation up to 200 mA**

- **At higher current excitation of the longitudinal CBM:**

  - generated probably by HOM's of the normal conducting cavity system.

- With *tuned cavity*, user operation at 400 mA.

3rd harmonic system global voltage ~700 KV - normal conducting system global voltage 2.2 MV

-The additional Landau damping from the harmonic system suppress the longitudinal CBM.

Amplitude loop disabled, tune adjusted for max lengthening at 400 mA.

SLS operation during early commissioning

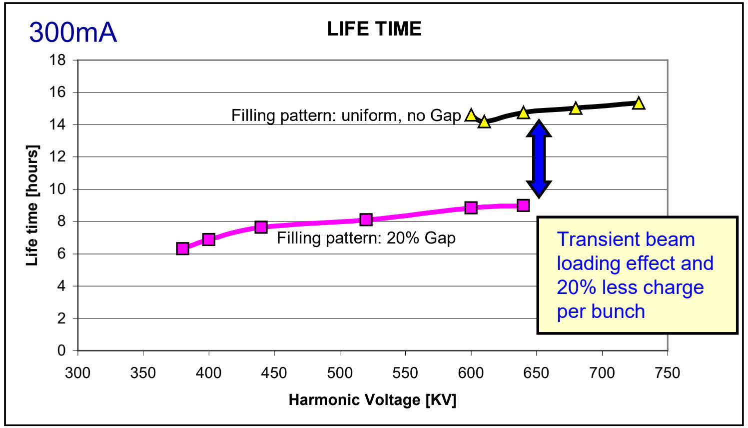
I>200 mA **without S3HC cavity** ⇨strong

excitation **of longitudinal CBI** (operation not possible).

I=400 mA **top-up** operation reached **with S3HC** cavity.

CBI completely damped between 0 and 400 mA.

Tuning can be kept constant while injecting up to 400 mA (max elongation at 400 mA).



Streak camera measurements

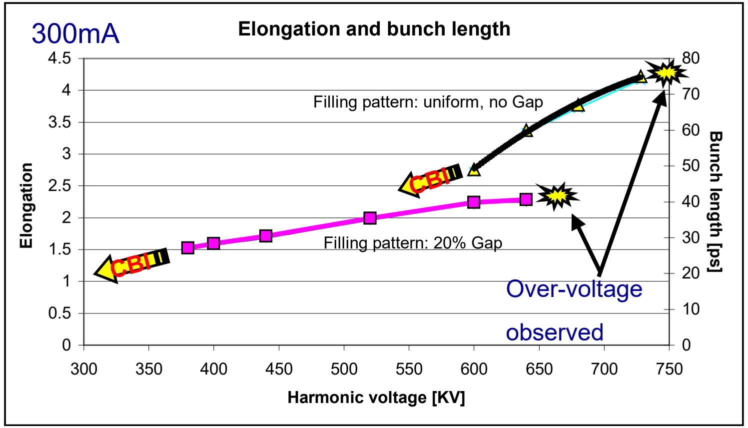
s=18ps at 200 mA without S3HC cavity

Life time without S3HC:

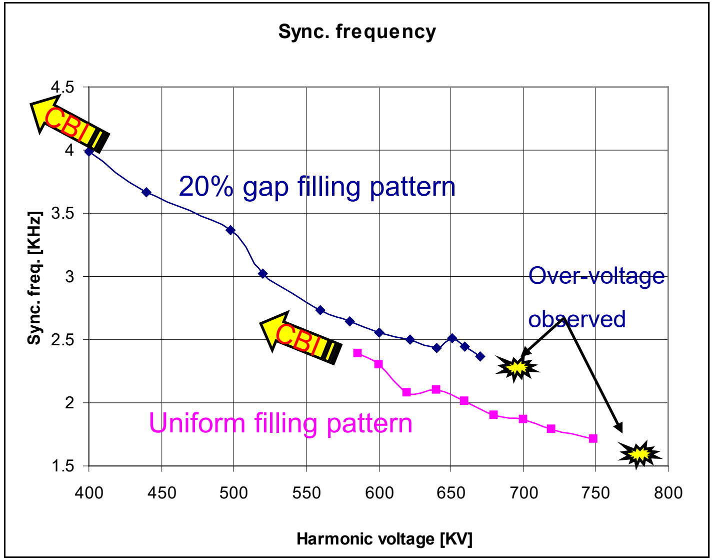
~ 4.6 - 5 hours @ 300 mA

No automatic tuning needed because of Top Up

No HOM observed from S3HC!



Sync. freq. spectrum broadening , and transient beam loading effect

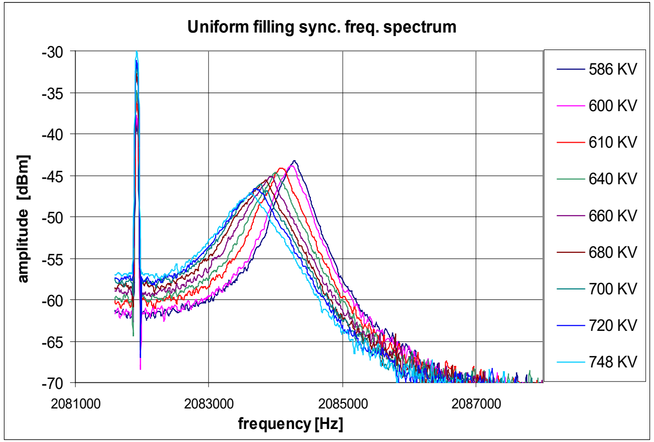


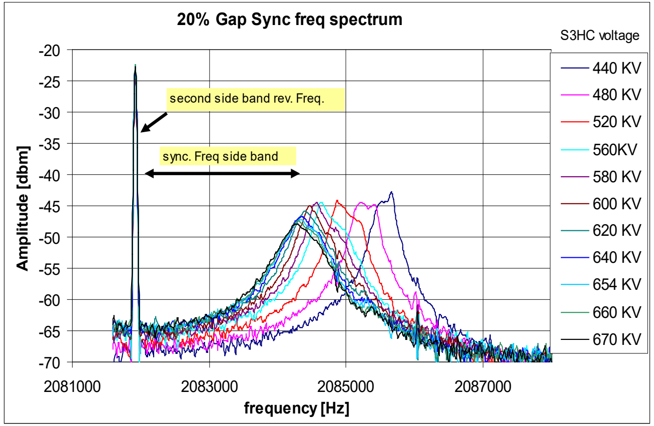
With 20% gap, broadening increases at low voltages due to transient beam loading (more efficient Landau Damping), but:

⇨ average lengthening reduced

⇨ average lifetime gain reduced

Sync freq. Spectrum broadening ⇨ Landau damping





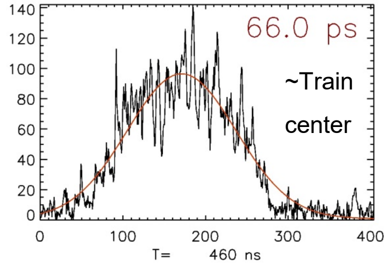
Transient beam loading effect

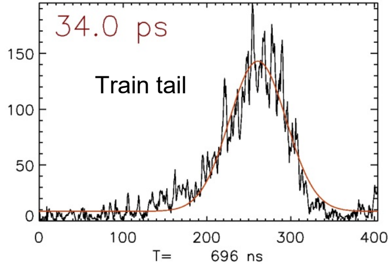
Streak camera snap shot example

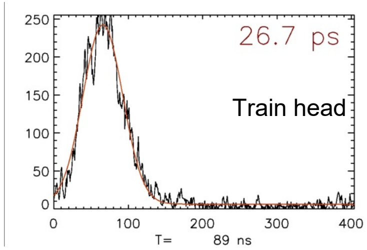
Ib=330 mA

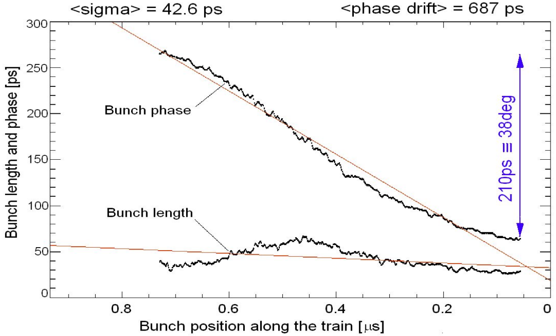
$V_{harmonic}$~660 KV

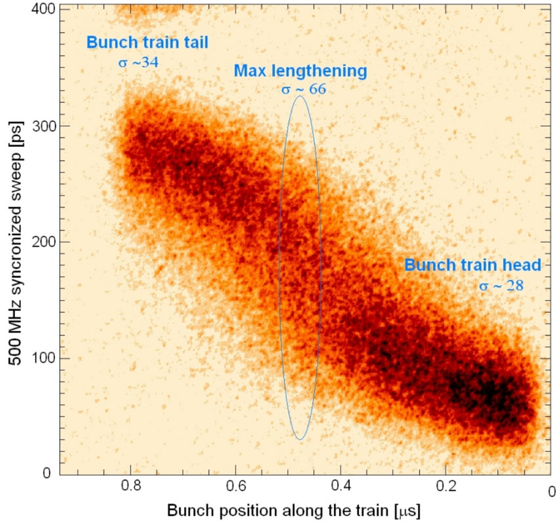
Close to maximum elongation











Faillures and Problems

- Cavity isolation vacuum shows some very fast spikes that seem related to a leak versus the air
- One leak on the coaxial line of HOM coupler repaired with fluid silicon
- Vacuum leak in the vacuum flange repaired with glue
- Turbine failure
- SLS emergency-stop button was pushed several times accidentally and switched off the cryogenic system. Now independent of SLS emergency stop button.

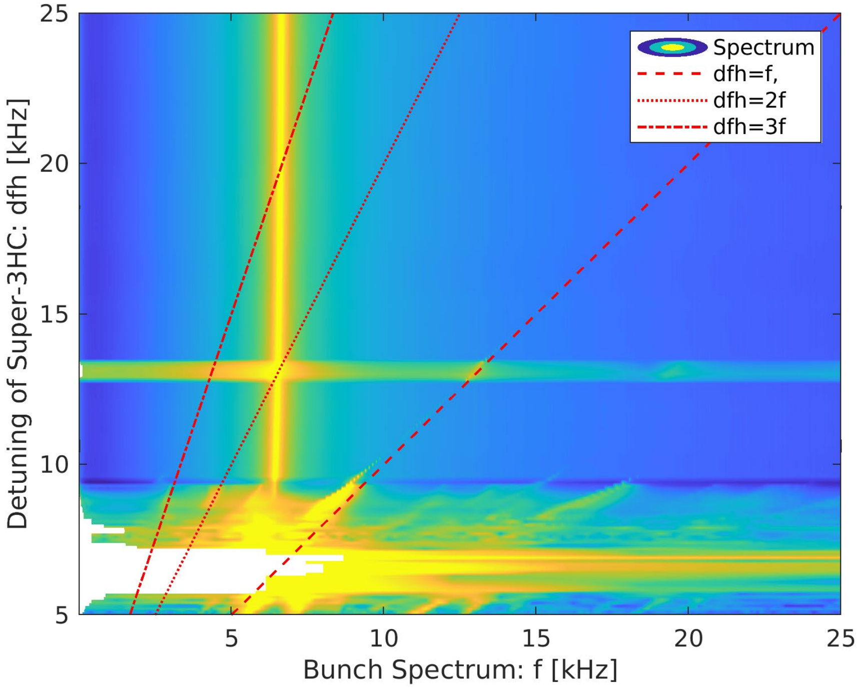
Settings for elegant Simulations

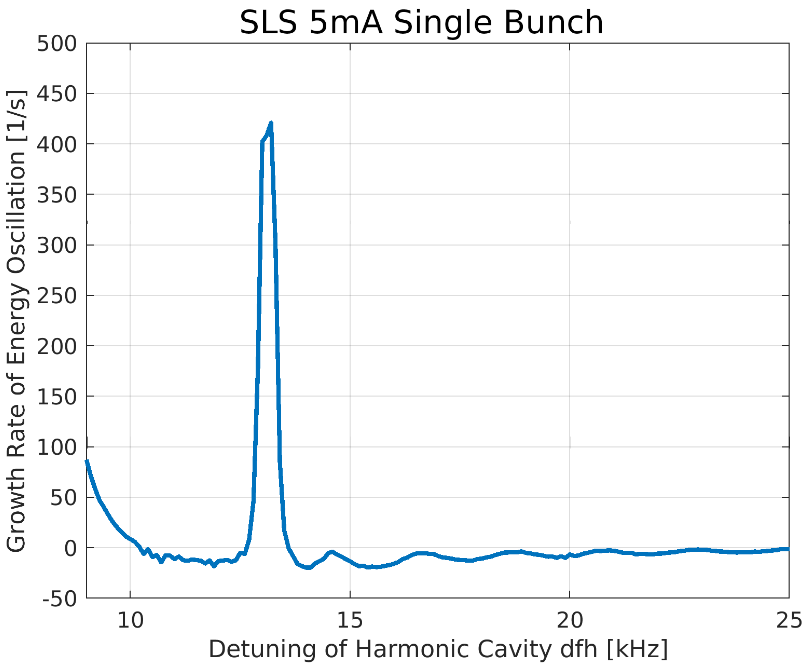
- # Main cavity voltage
- set Vc 2.2 [MV]
- set dfm 0 [kHz]
- set Qm 40e3
- # Loaded Q
- set Qlm 13.333e3
- # Ra/Q (Ra=V^2/P)
- set RaOQm 156 [Ohm]
- # Harmonic number
- set mh 480
- # Number of cavities
- set nm 4

- # Parameters of the harmonic cavities
- # Loaded Q
- set Qlh 1.6e8
- # Relative harmonic
- set hh 3
- # Ra/Q (Ra=V^2/P)
- set RaOQhnom 88.4 [Ohms]
- # Number of cavities
- set nh 2

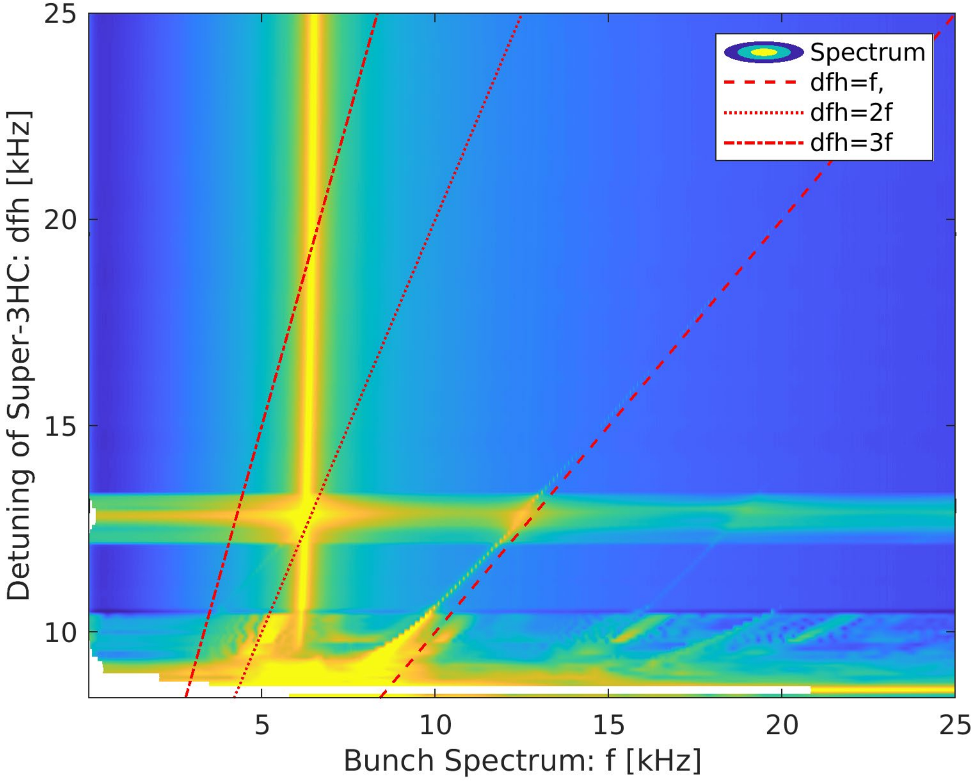
- No broad-band impedance included.
- 100’000 turns
- About 6’000 macro partices/bunch for multibunch

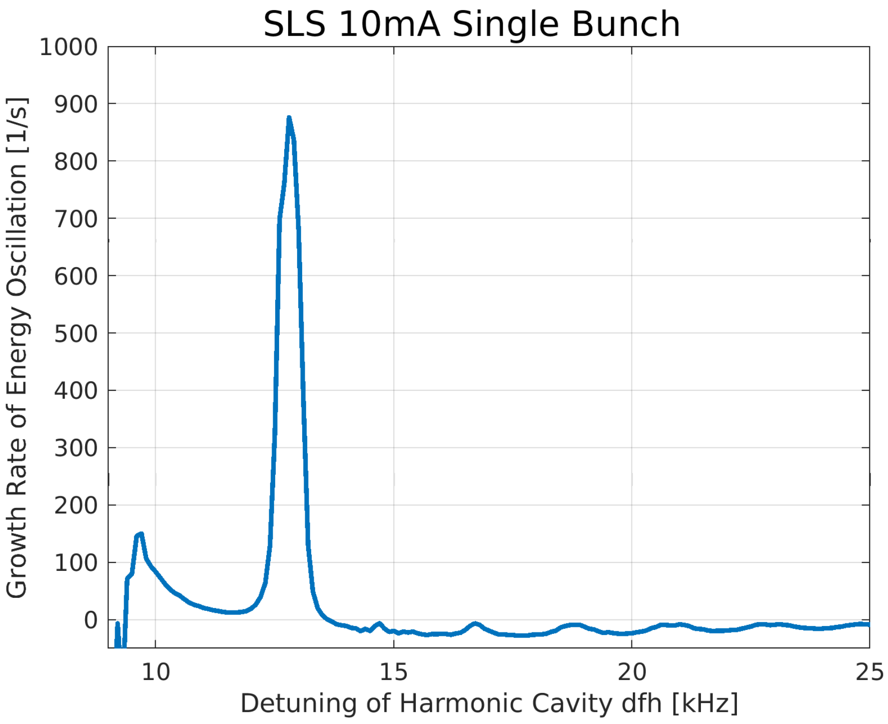
5mA, Single Bunch



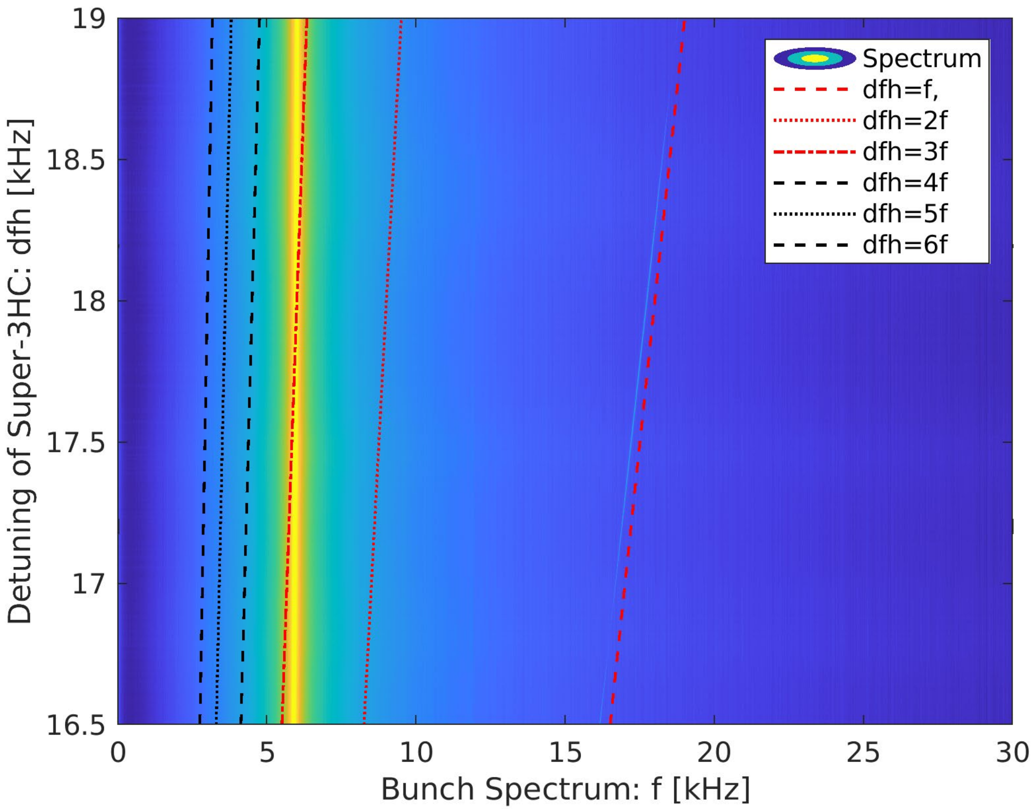


2x5mA=10mA (2 Bunches)

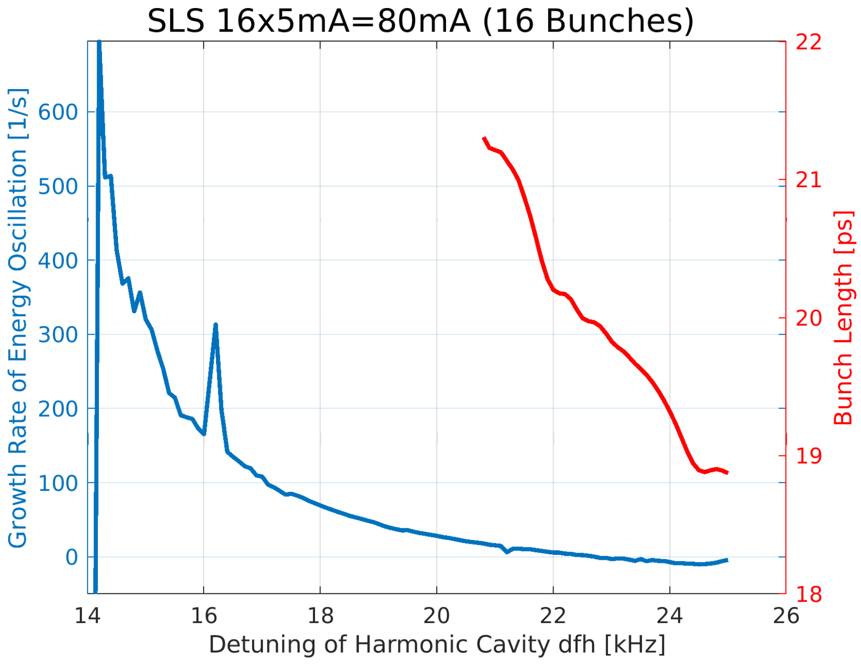


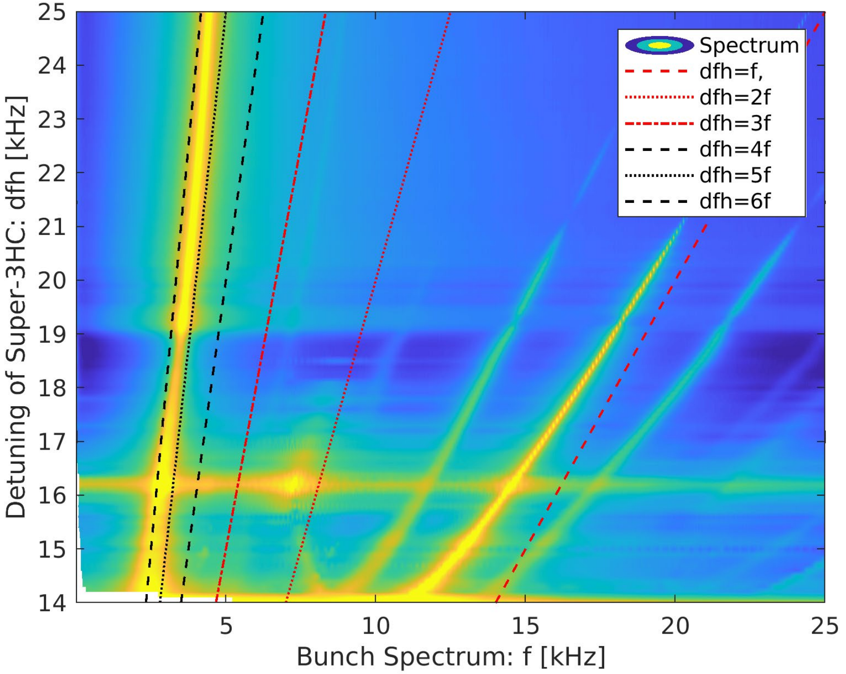


20mA case (with fine steps in detuning)

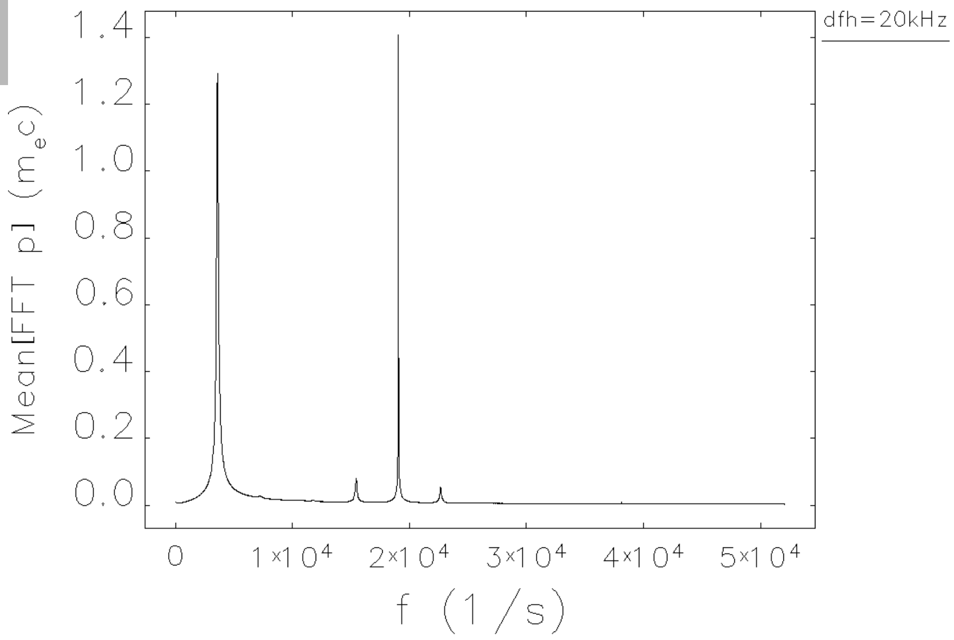


16x5mA=80mA (16 Bunches)

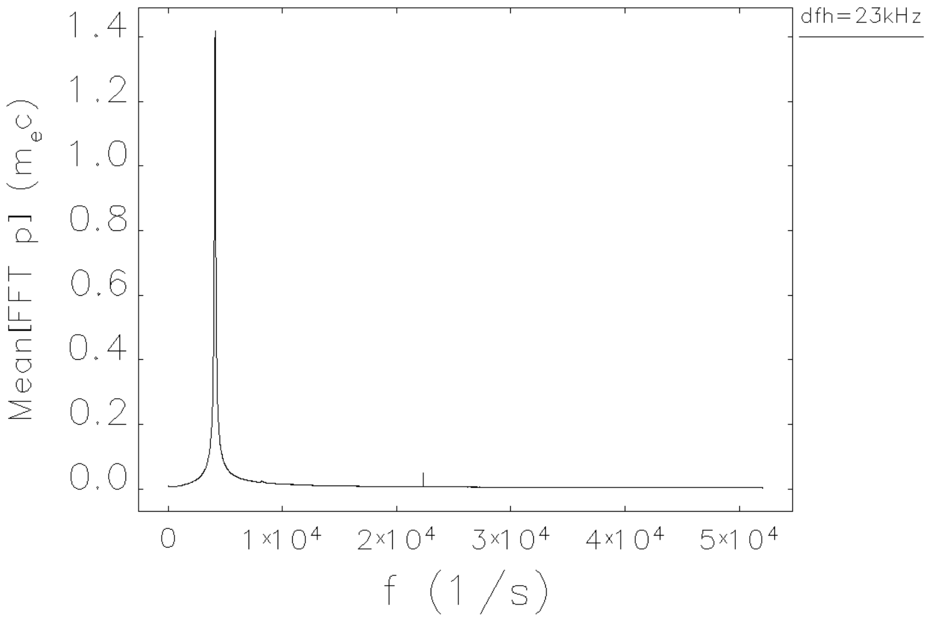




Spectrum at 80mA, 20kHz and 23kHz case

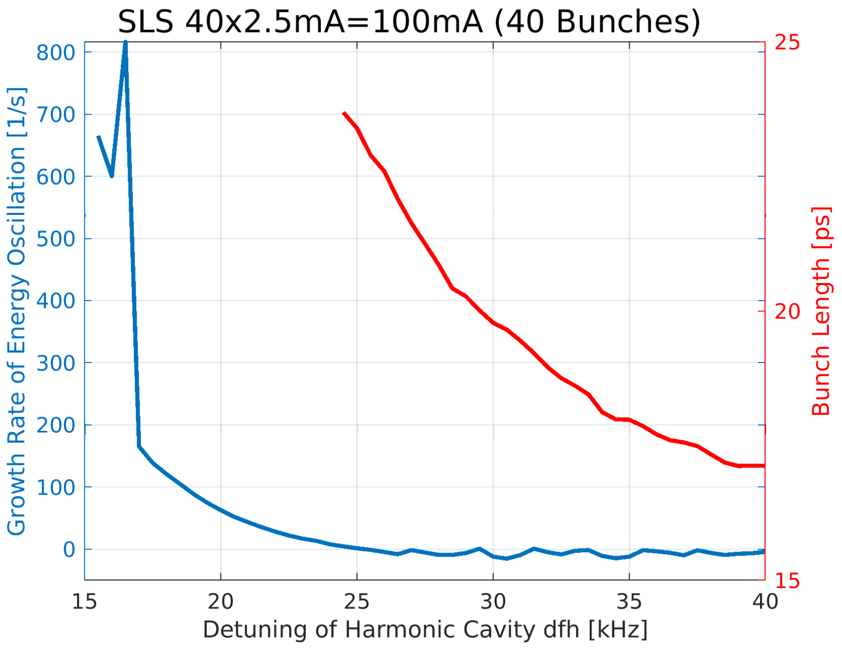


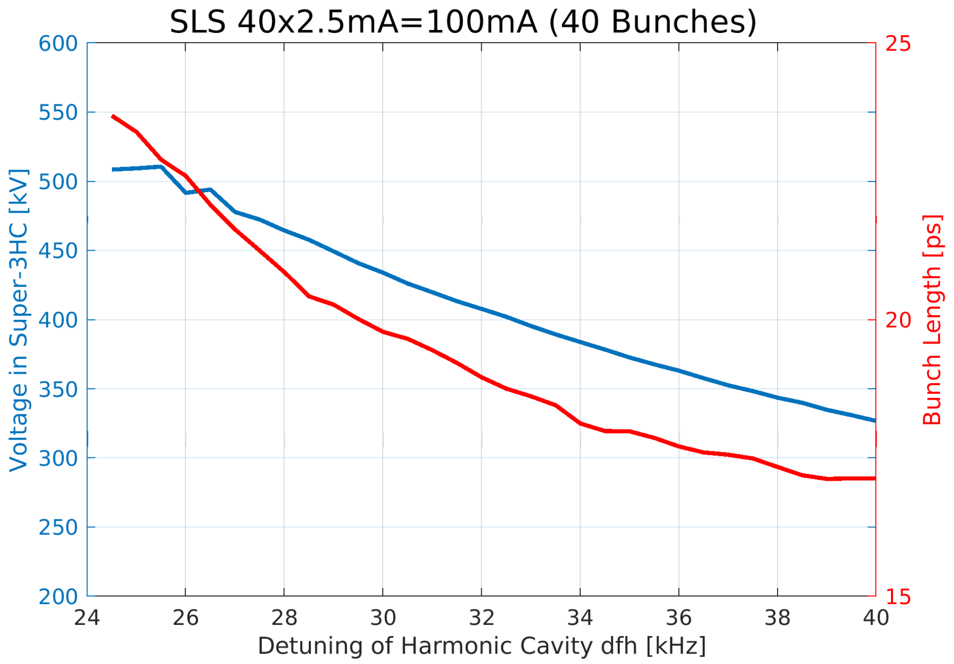
Spectrum averaged over macroparticles @ 80mA



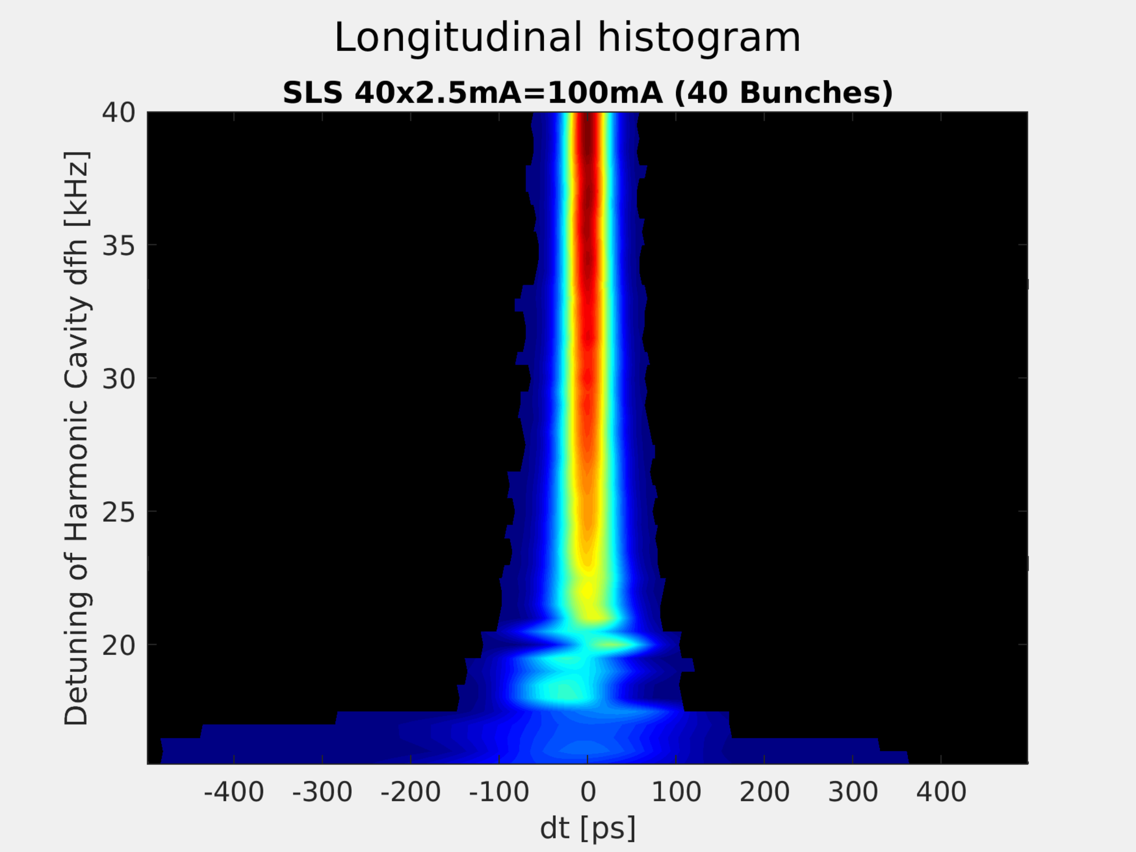
Spectrum averaged over macroparticles @ 80mA

40x2.5mA=100mA (40 Bunches)

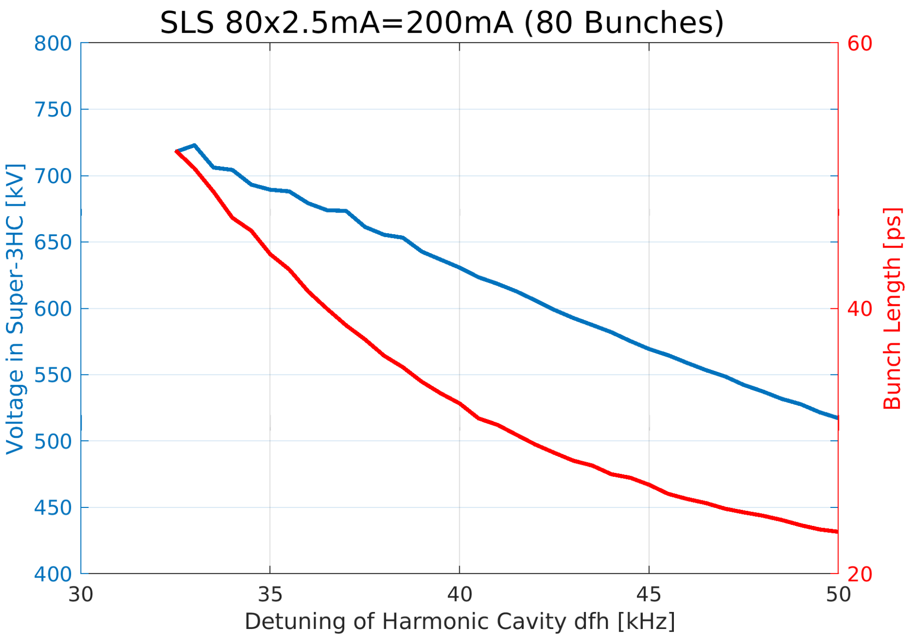


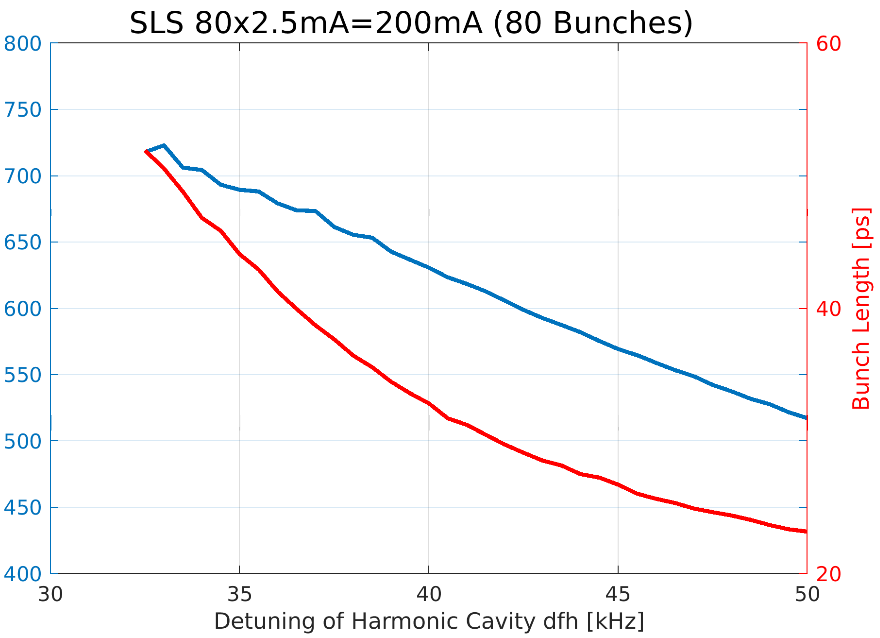


40x2.5mA=100mA (40 Bunches)



80x2.5mA=200mA (80 Bunches)





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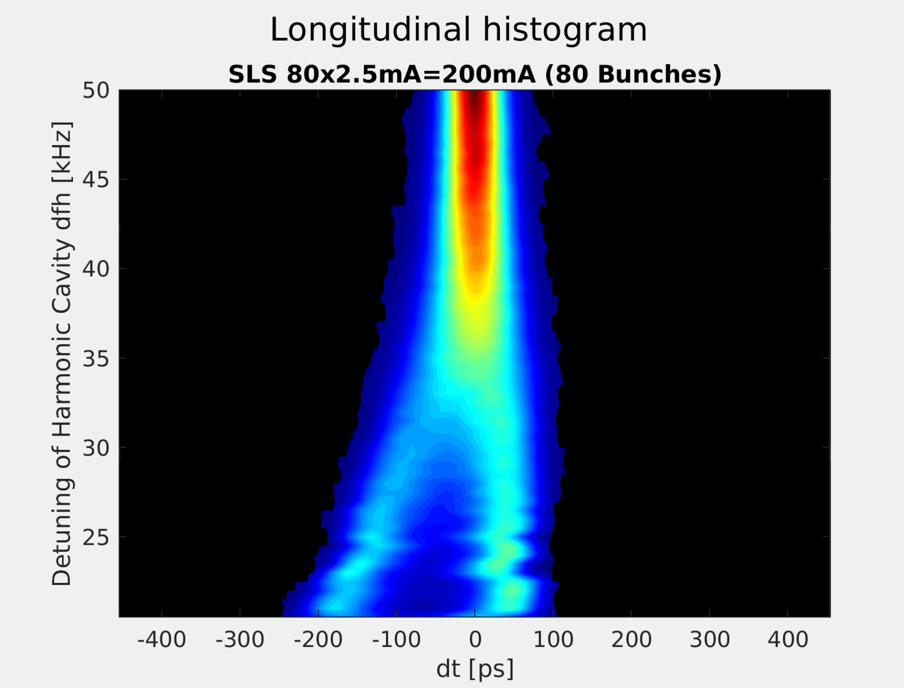
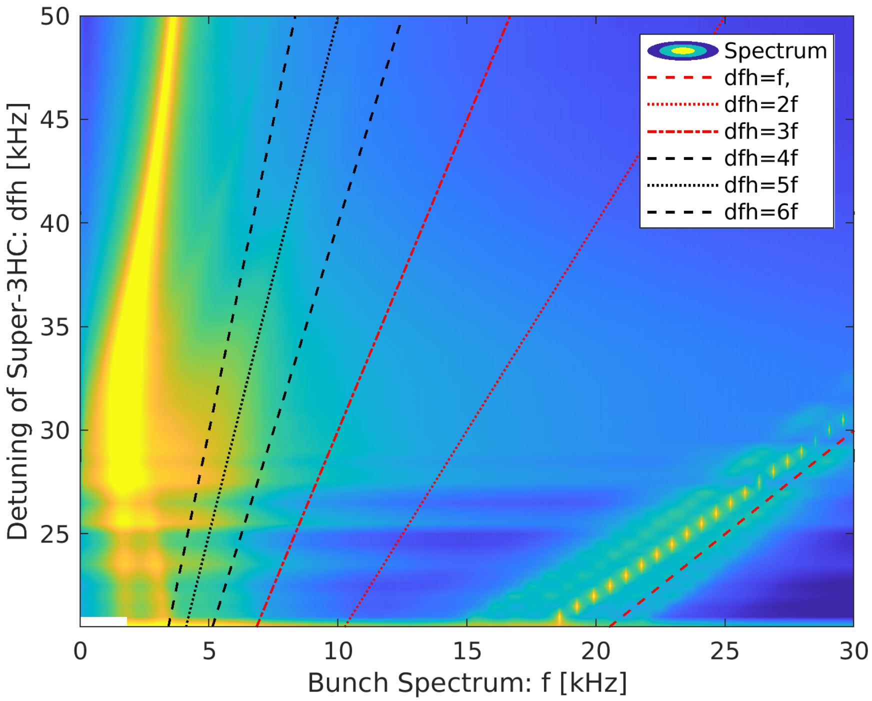
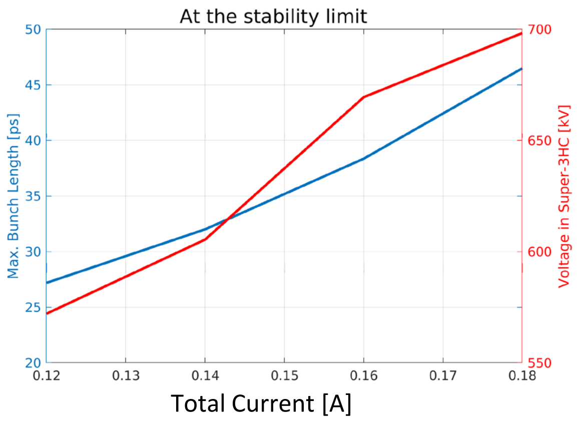
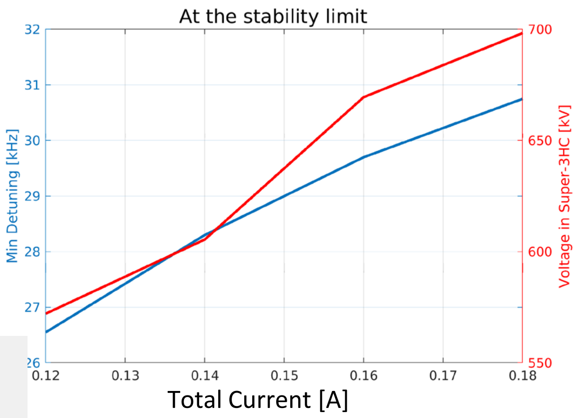
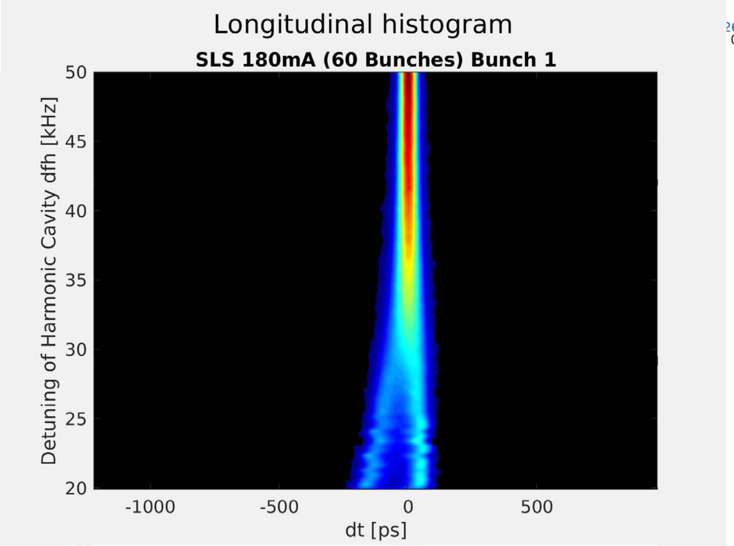




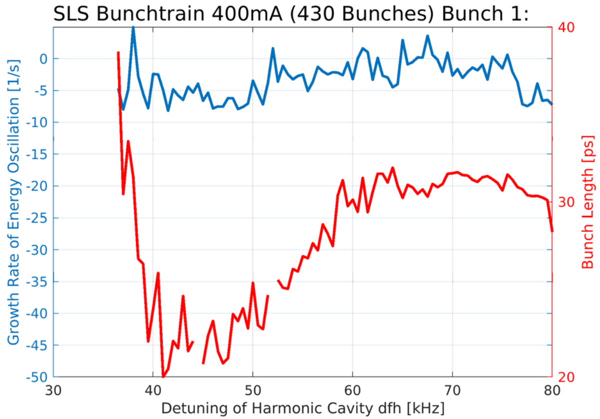
Search for the Limit of Bunch Lengthening

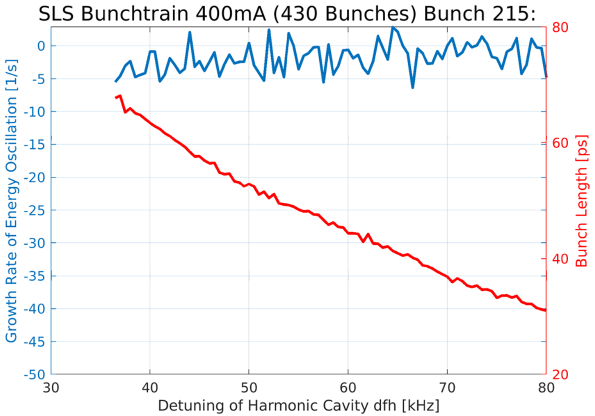


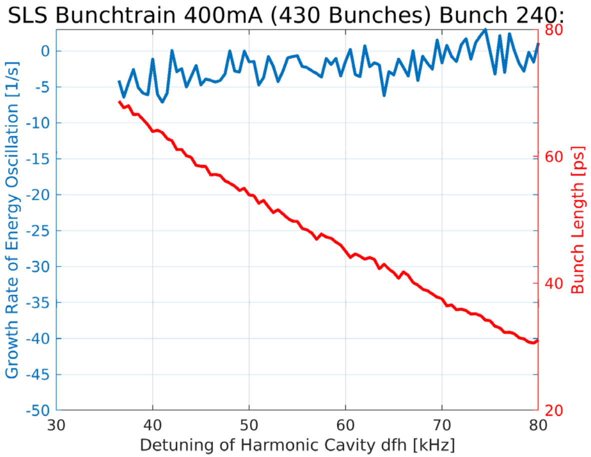


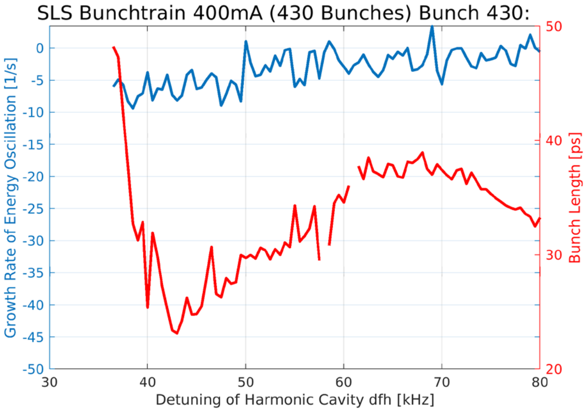


400mA, 430 Bunches filled out of 480









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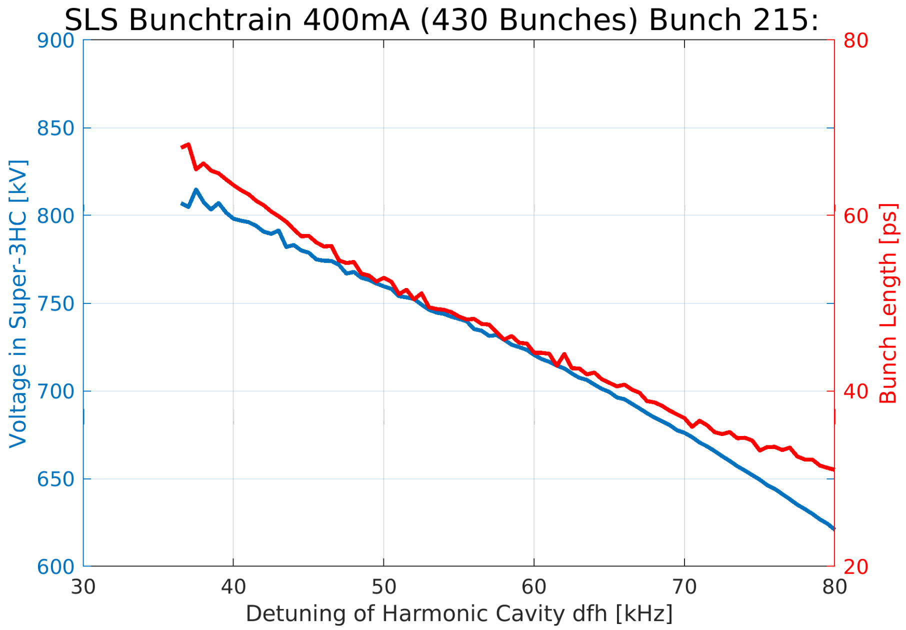

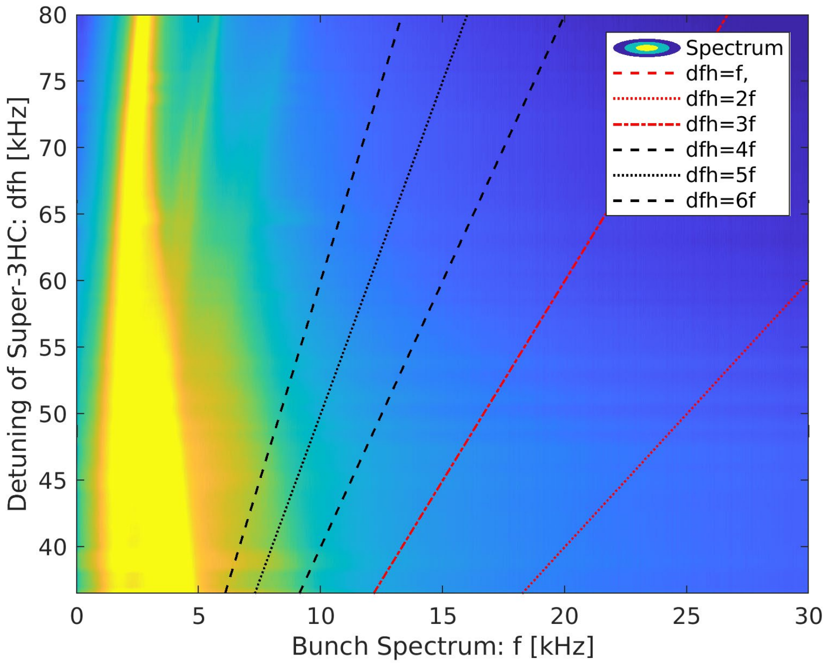

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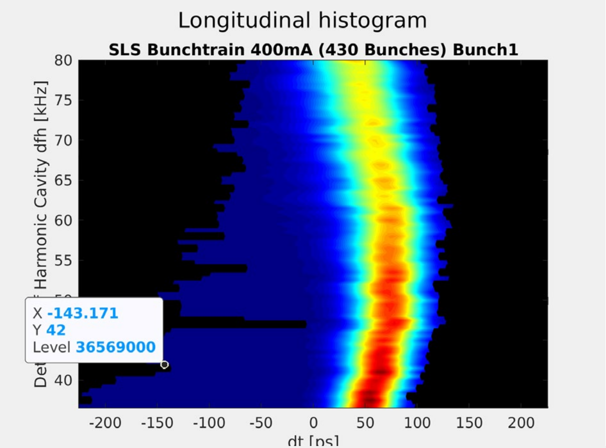

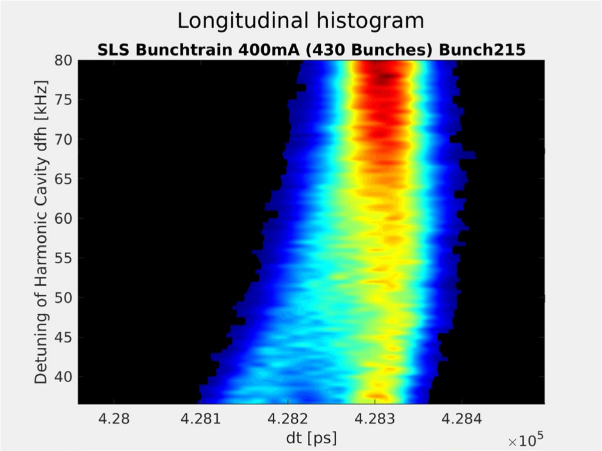

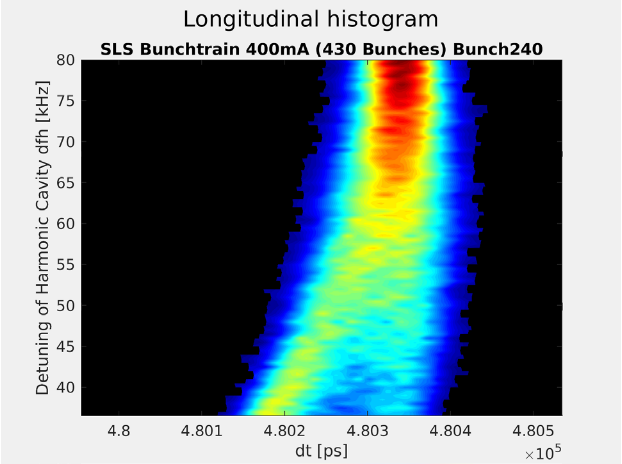

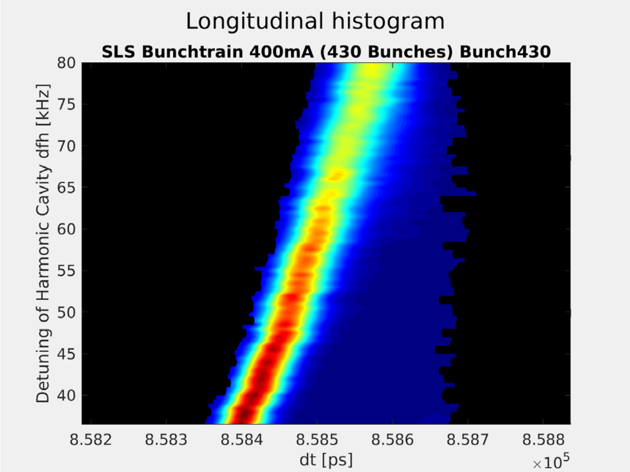

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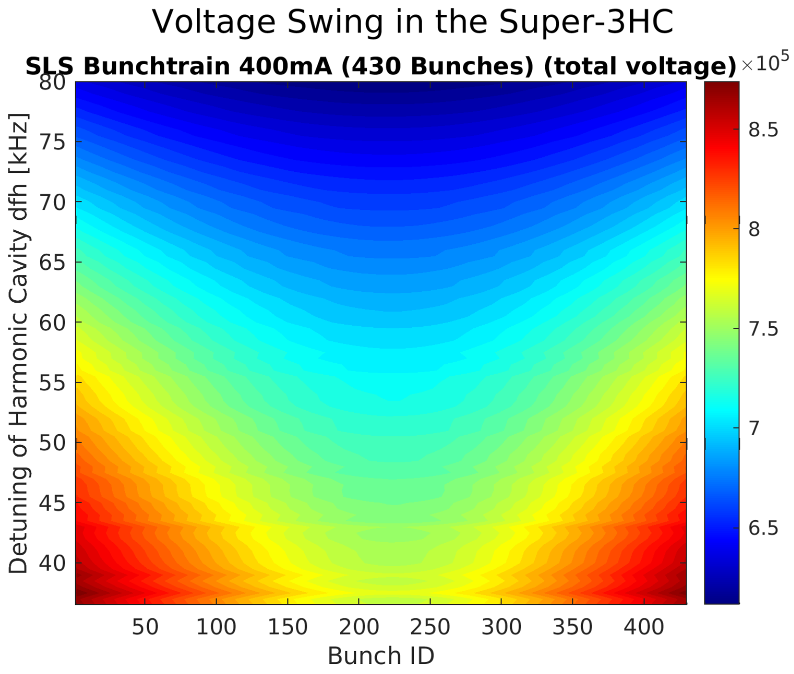
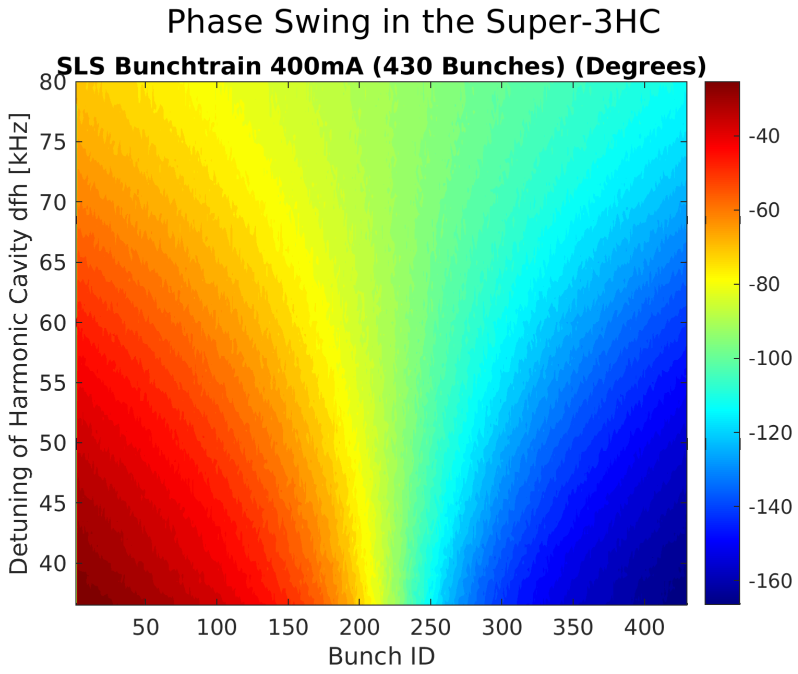


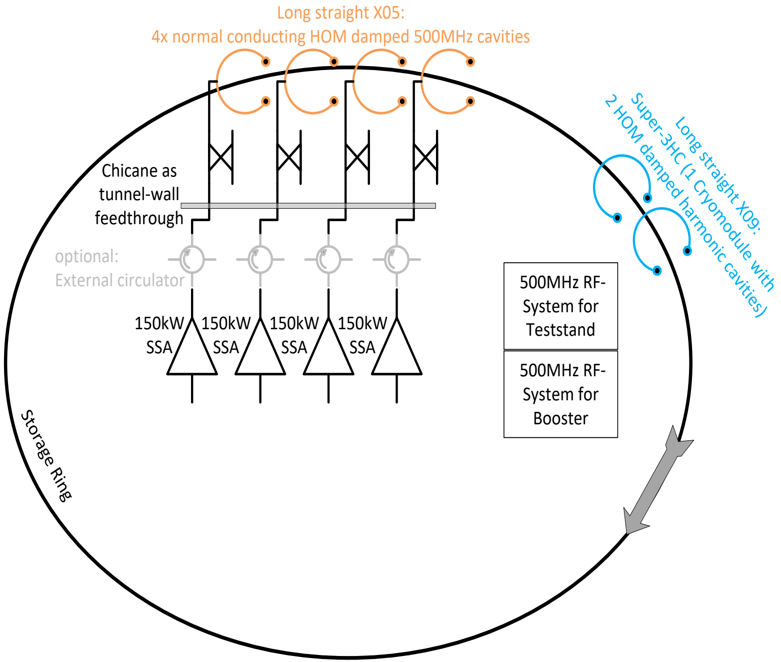


SLS 2.0 Synchrotron Parameters (minor changes)

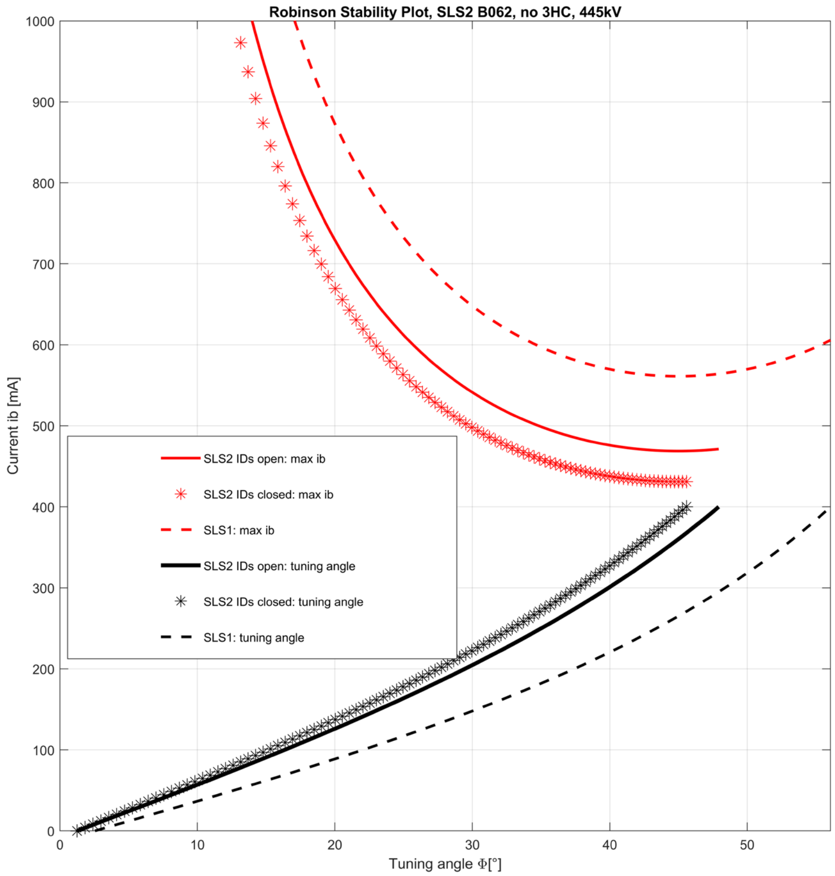
	SLS 2.0 (TDR)	SLS
Circumference [m]	288	288
Energy [GeV]	2.7	2.411
Lattice and ID Energy loss/turn [keV]	687.6 → **943**	549→600
Energy loss/turn in wake fields [keV] w. (w.o) 3HC	7 (22)	
Energy spread	$1.16 \cdot 10^{-3}$	$9 \cdot 10^{-4}$
Momentum compaction α_c	$1.05 \cdot 10^{-4}$	$7 \cdot 10^{-4}$
Energy acceptance (without harmonic cavity)	6.2% → 5.1%	3%
Main RF frequency [MHz]	499.6537	499.6
Total main RF voltage nominal [kV]	1780	2080
Total main RF voltage maximum [kV]	2200	2600
Harmonic number	480	480
Gap in the filling pattern, empty buckets	20…**30**	50…90
Damping times x/y/E [ms]	4.14/7.54/6.41	8.4/8.4/4.5
Longitudinal stability threshold per cavity [GHz kΩ]	6.2	
Horizontal stability threshold per cavity [MΩ/m]	3.3	40
Vertical stability threshold per cavity [MΩ/m]	4.4	
Beta functions at main cavity location β_x [m] / β_y [m]	9.6/7.0	1.5/1.1
Beta functions at harmonic cavity β_x [m] / β_y [m]	6.8/4.1	3.5/3.5
Synchrotron frequency without harmonic cavity [kHz]	2.172	6.93
Energy fluctuations relative to energy spread	<10%	

SLS 2.0 RF parameters

Main RF-System	SLS 2.0		SLS
Total voltage [kV]	1440	1780	2080
Energy acceptance (without harmonic cavity)	5% → 3.7%	6.3% → 5.2%	3%
Number of cavities	4		4
Voltage per cavity [kV]	360	445	520
Wall loss per cavity [kW]	20	30	40
Required RF-power with beam and minimum ID Power [kW]	88	98.1	95
Required RF-power with beam and maximum ID Power [kW]	114	**124**	100
Optimal coupling	4.62…6.0	3.4…4.3	2.5
Detuning for matching [kHz]	-49.1…-57.1	-32.4…-44.6	-33
HOM control	**By strong HOM damping**		Temp. detuning
Max. voltage for ≤150kW reflected pulse power [kV] (restriction from amplifier specification)	460	540	

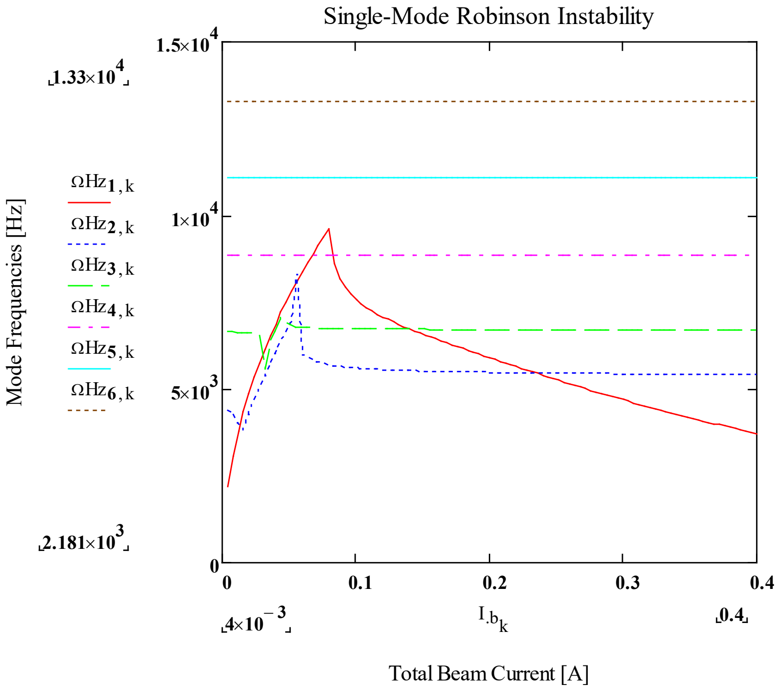


Robinson Instability SLS 1 and SLS 2.0 without Harmonic Cavity

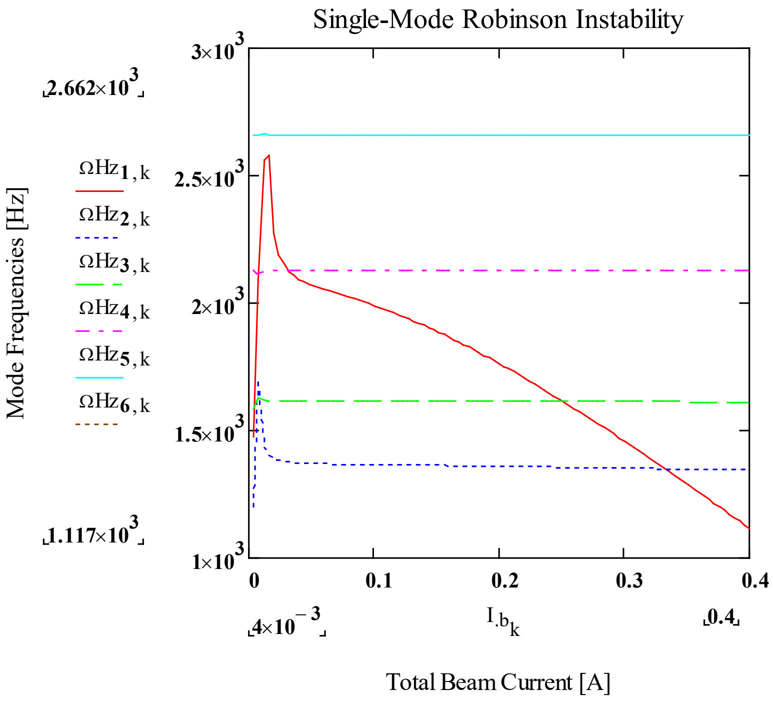


According to R.A. Bosch's paper:
«Robinson instabilities with a higher-harmonic cavity» (PRSTAB 4,074401 2001)

SLS 1:

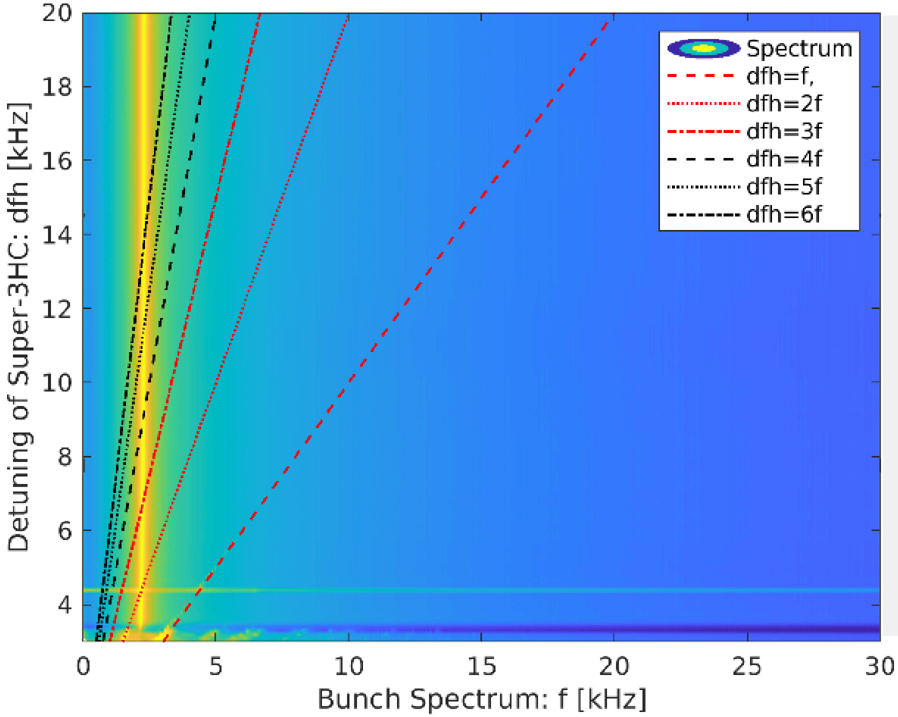


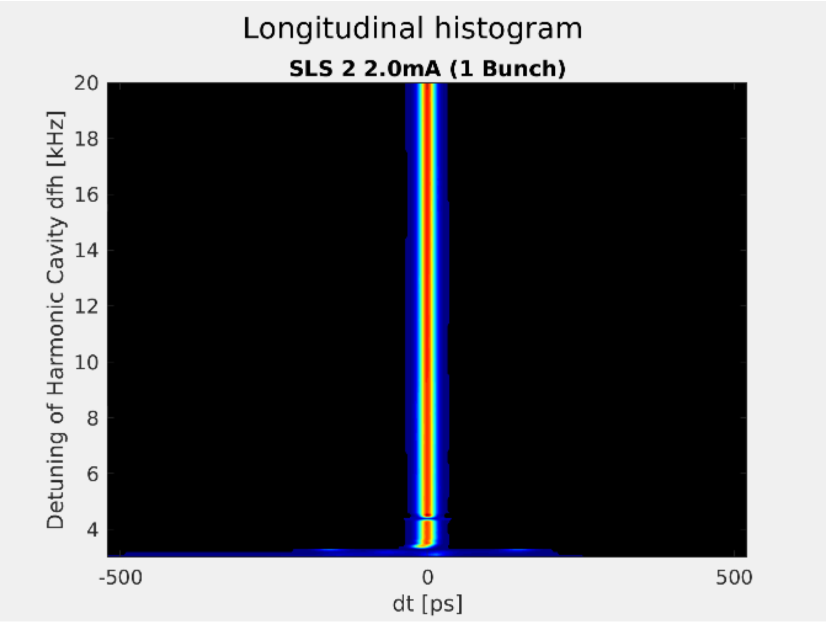
SLS 2:



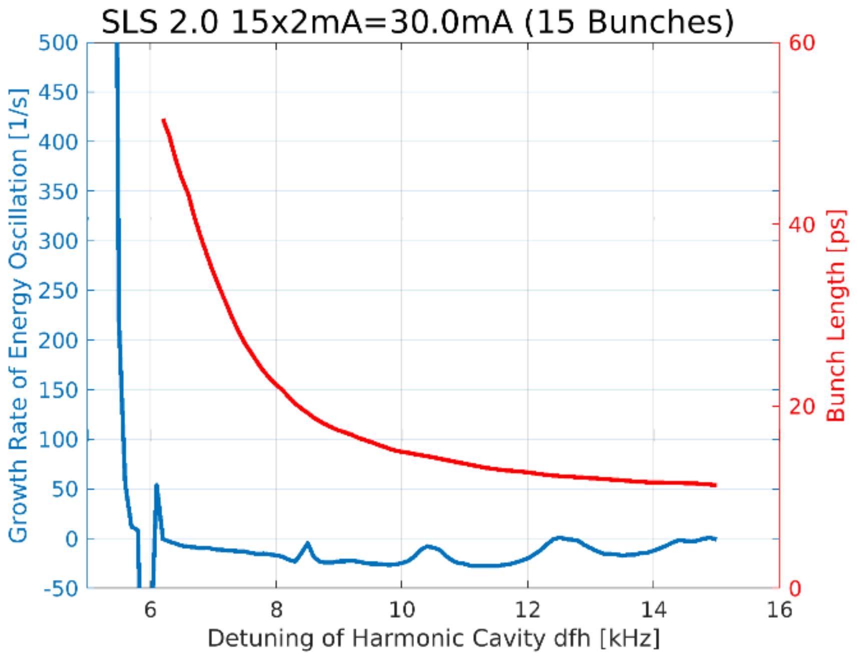
Preliminary Results
from MathCAD

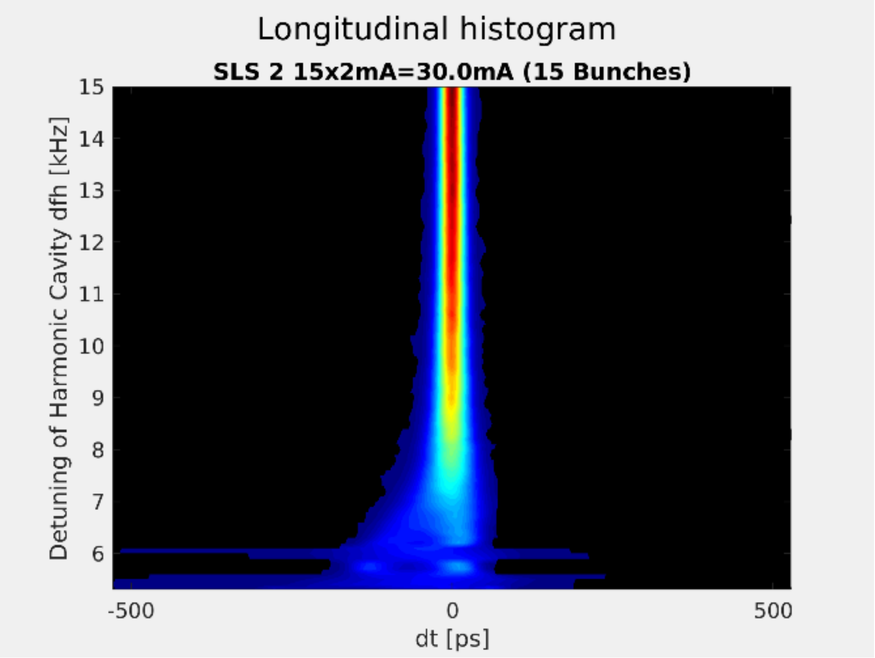
SLS 2.0: Low Current Case at 2mA





SLS 2.0: Low Current Case at 30mA





PAUL SCHERRER INSTITUT

Wir schaffen Wissen – heute für morgen

Thanks for your comments!

Simulations were performed with “elegant”:

M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation," Advanced Photon Source LS-287, September 2000