PAUL SCHERRER INSTITUT

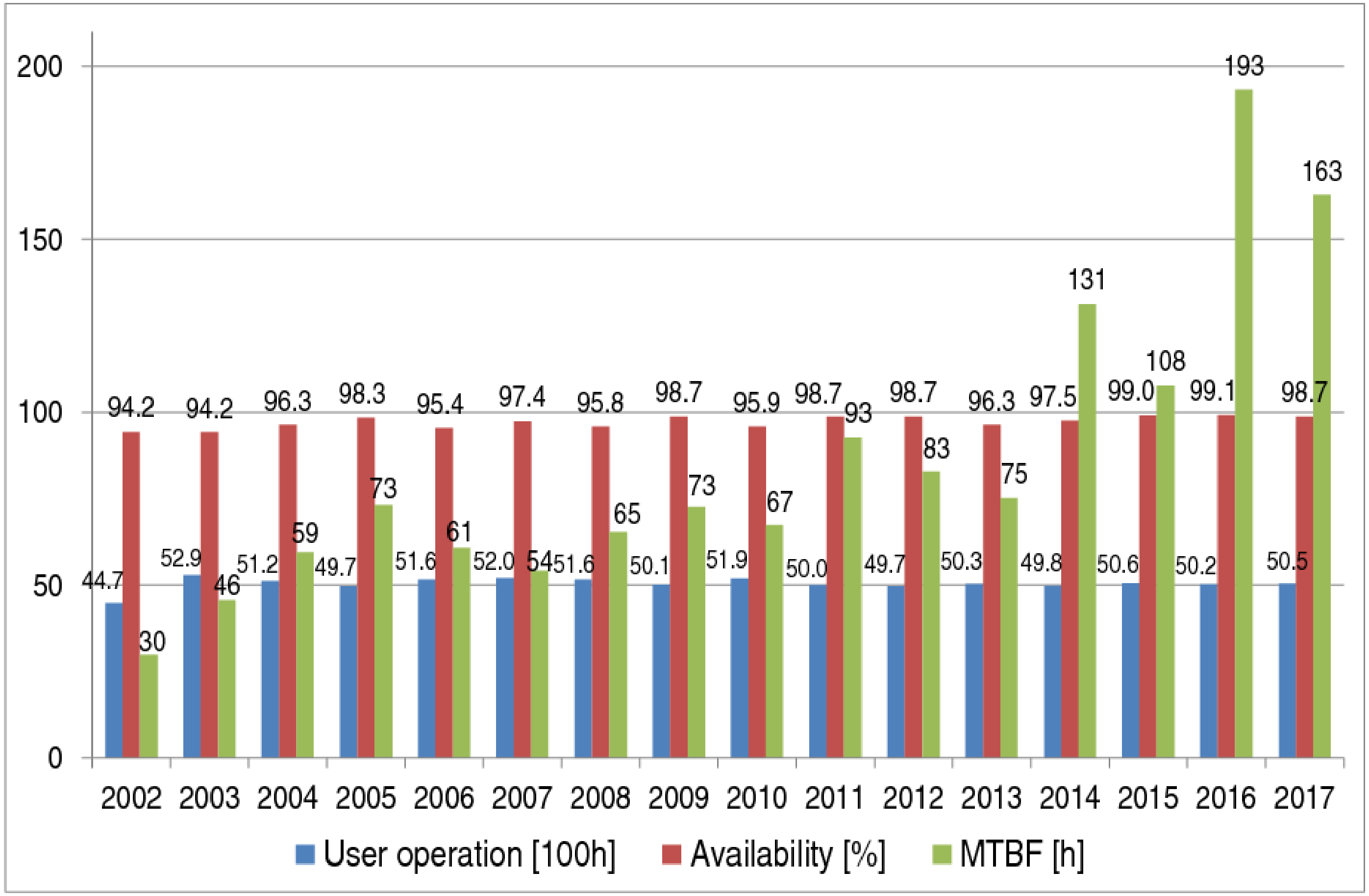

WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

Lukas Stingelin :: Group RF Systems 1 :: Paul Scherrer Institut

SLS RF operation and status of the SLS-2 project

22nd ESLS-RF workshop, from 8th November to 9th of November 2018,
Synchrotron SOLEIL, Gif-sur-Yvette Cedex, France

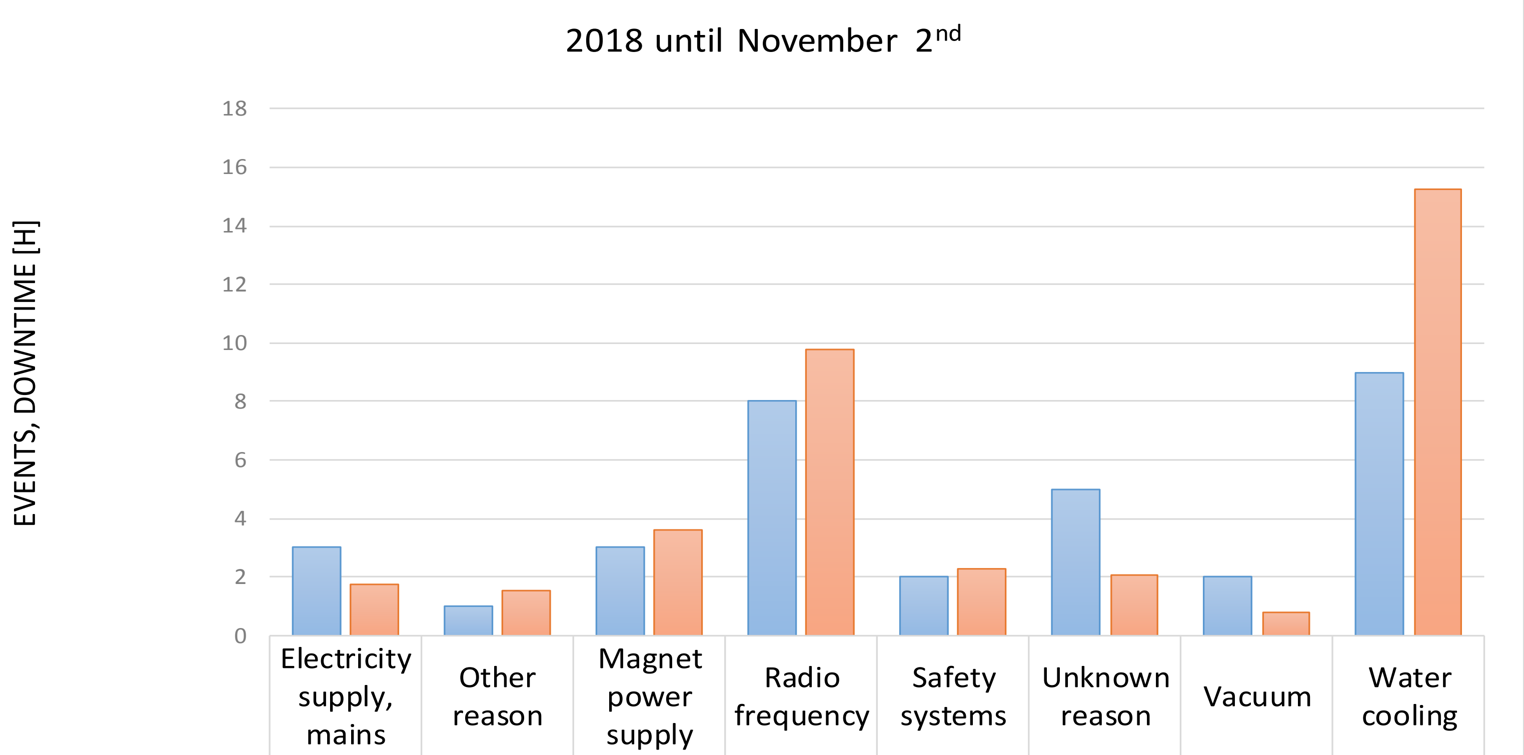
SLS Operation Statistics



Main issues in 2017:

- water leak in photon absorbers
- Broken rectifier in magnet power supply

SLS Operation Statistics 2018


2018 until November 2^{nd}

	Electricity supply, mains	Other reason	Magnet power supply	Radio frequency	Safety systems	Unknown reason	Vacuum	Water cooling
🟦 Events	3	1	3	8	2	5	2	9
🟧 Down time [h]	1.76	1.53	3.61	9.77	2.25	2.04	0.8	15.26

Main reasons for RF events:

- Drifts and settings of interlock thresholds (~4h)
- Klystron vacuum and modulation anode overcurrent (~3h)
- Loose contact in cooling rack (~1.5h)
- Flow switches (~1h)

SLS RF works

Done:

✓LINAC PFN: Capacitor replacement
✓LINAC PFN: Thyratron replacement
✓LINAC pulser board spare
✓LINAC dump switch upgrade
✓LINAC: Sample&Hold box spares
✓Booster: Controls integration and operation with solid state amplifier

In Progress:

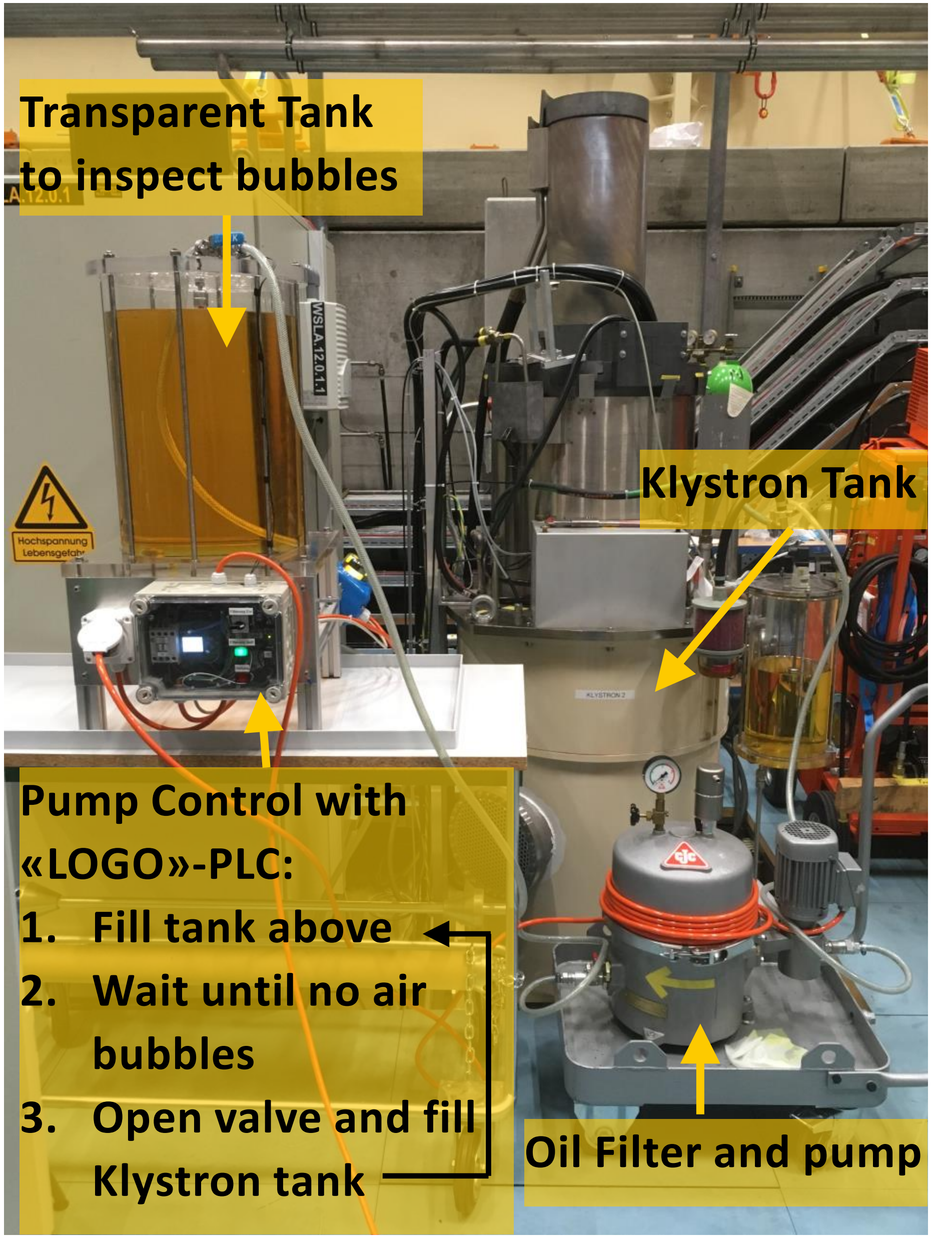
☐ LINAC isolation Oil treatement
☐ LINAC pulser board upgrade to shorter bunches
☐ LINAC spare structures?
☐ LINAC LLRF-upgrade → «SwissFEL»
☐ Storage-Ring: Klystron optimization
☐ Storage-Ring: HOMFS upgrade
☐ Storage-Ring: LLRF upgrade
☐ Storage-Ring: HOM-absorber investigation
☐ Super-3HC: Controls interface
☐ Refurbishment of 500MHz Klystrons from Daresbury

Problems with Air bubbles and Oil filtering in the LINAC

- ❖ Outage during last ESLS-RF workshop: **Arcing in the Klystron tank** prevented operation
- ➢ **Air bubbles** accumulated under the Klystron plug → bubbles floating up caused arcs
- ❖ Mobile oil treatement plant helped against the bubbles, but reduced high voltage capability

- ➢ **Improved setup with filter→**

(Courtesy of D. Kunz)



Transparent Tank to inspect bubbles

Klystron Tank

Pump Control with «LOGO»-PLC:

1. **Fill tank above**
2. **Wait until no air bubbles**
3. **Open valve and fill Klystron tank**

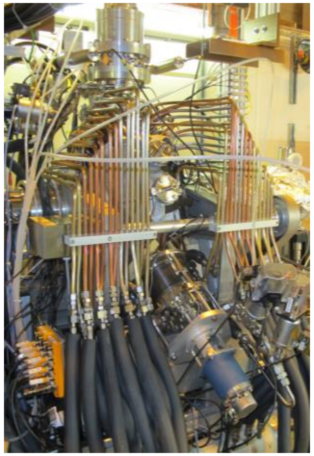
Oil Filter and pump

Specification for SLS1&2 Main RF-System

	SLS 2					**SLS**
Total voltage [kV]	**1200**		**1400**		**1800**	**2080**
Energy acceptance	4.2%	4.2%	5.0%	5.0%	6.4%	3.0%
Number of cavities	2	3	3	4	3	4
Voltage per cavity [kV]	600.0	400.0	466.7	350.0	600.0	520.0
Wall loss [kW]	57.7	25.6	34.9	19.6	57.7	43.3
Power with beam [kW]	177.7	105.6	114.9	79.6	137.7	103.3
Optimal coupling	3.1	4.1	3.3	4.1	2.4	2.4
Detuning for matching [kHz]	23.1	34.6	31.0	41.3	25.1	-33.0
Total RF power [kW]	**355.4**	**316.9**	**344.7**	**318.5**	**413.1**	**413.3**

RF-Noise specification: noise induced energy oscillation < 10% of Energy spread

Gap in Filling Pattern: ≥ 10 buckets

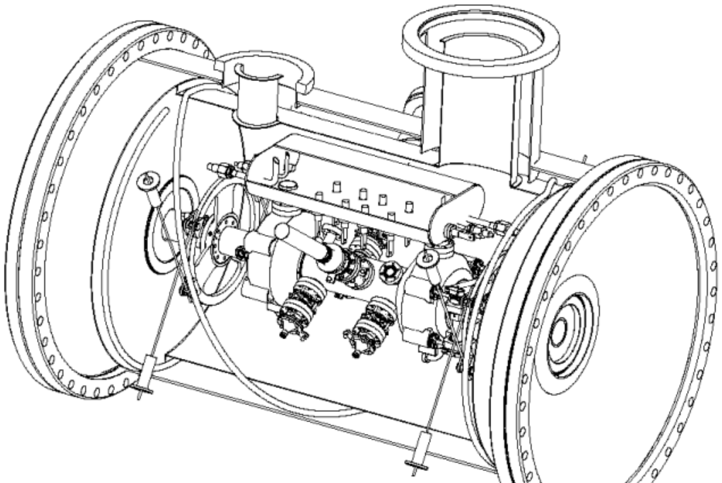


Green: normal operation of SLS2 with 3 cavities

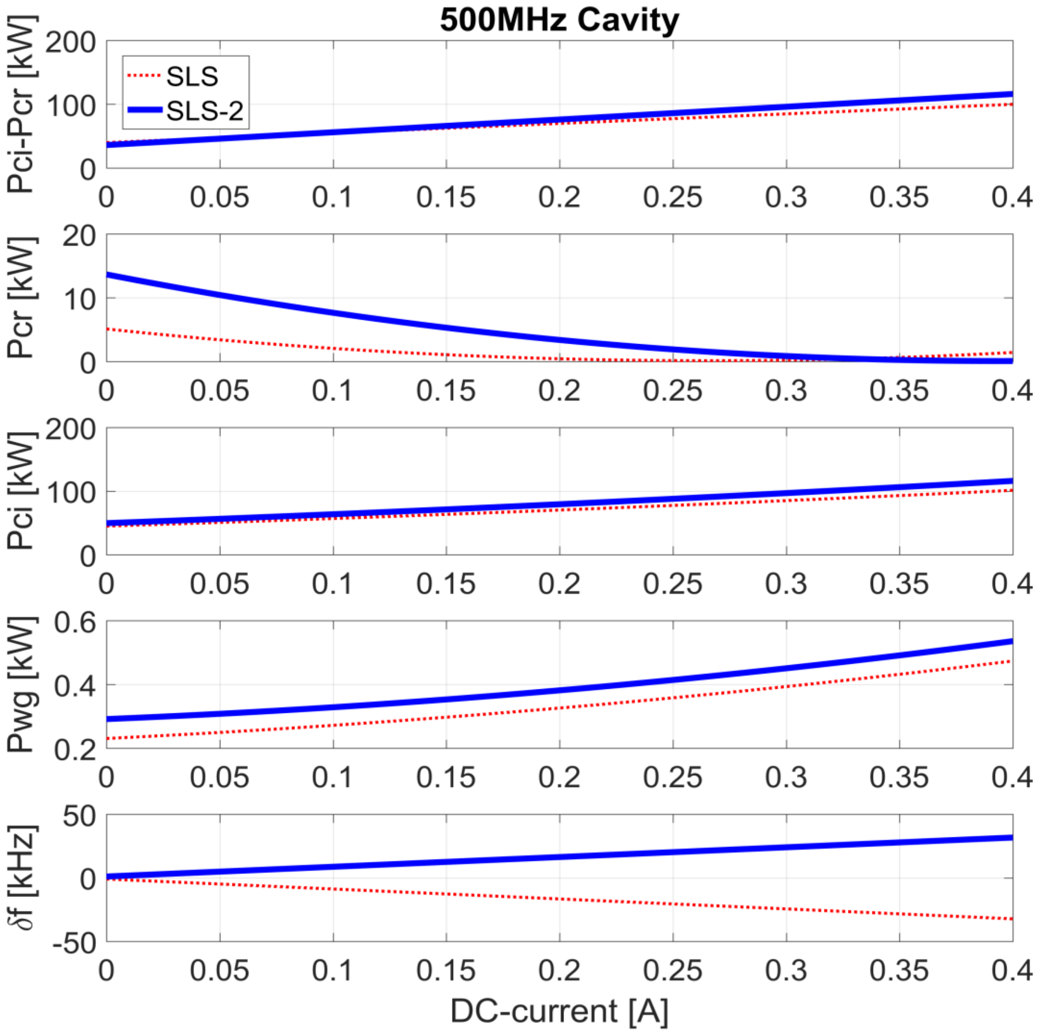
Orange: Backup solution with 2 cavities in SLS2

Specification for SLS1&2 Super-3HC

	SLS 2						SLS	
Total main voltage [kV]	**1200**		**1400**		**1800**		**2080**	**2080**
Harmonic voltage [kV]	0	340	0	423.1	0	561	0	690
Cryo load 1 cavity op. [W]	23.3	31.2	23.3	35.6	23.3	44.9	23.3	56.0
Cryo load 2 cavity op. [W]	23.3	27.3	23.3	29.5	23.3	34.1	23.3	39.7
Bunch length [ps]	9.8	45	8.9	42	7.7	38.4	14.7	50
Synchrotron frequency mean [kHz]	2.13	0.23	2.4	0.25	2.7	0.27	6.93	0.93
Synchrotron frequency spread [kHz]	-	0.15	-	0.16	-	0.17	-	0.592



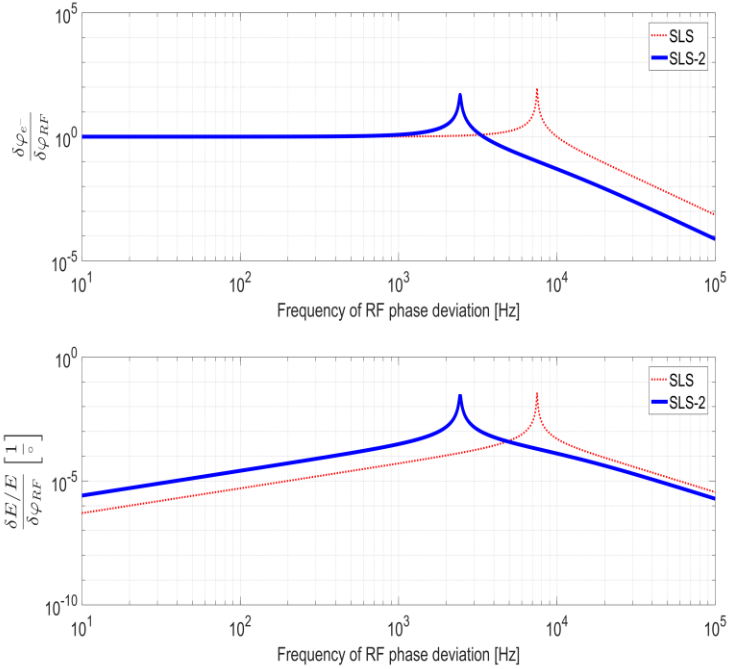
Power requirement for 3 cavity operation in SLS2 and normal operation in SLS1



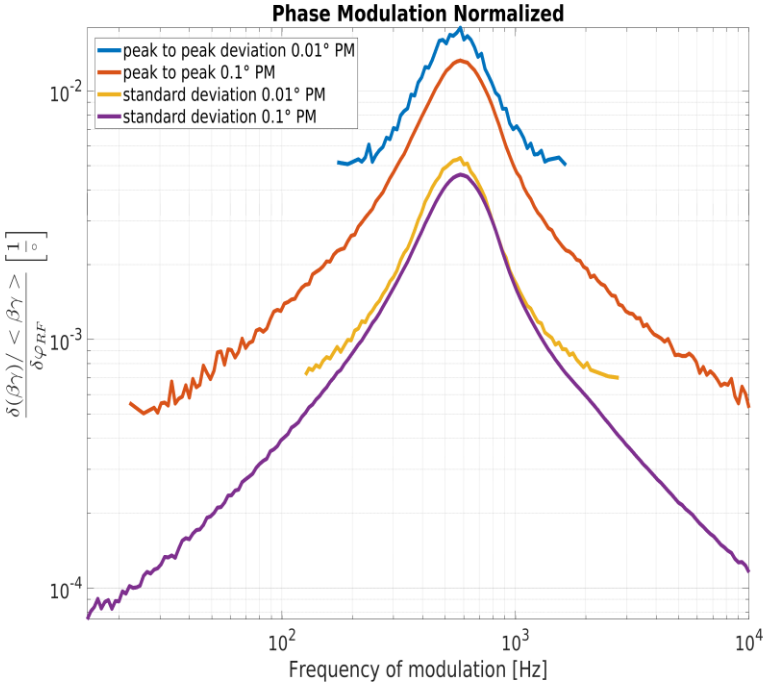
- Slightly increased power requirement for SLS2
- Higher **reflected power** without beam loading
- Detuning in other direction (negative momentum compaction)

SLS2 Noise Investigations

Without Harmonic Cavity



With Ideal Harmonic Cavity



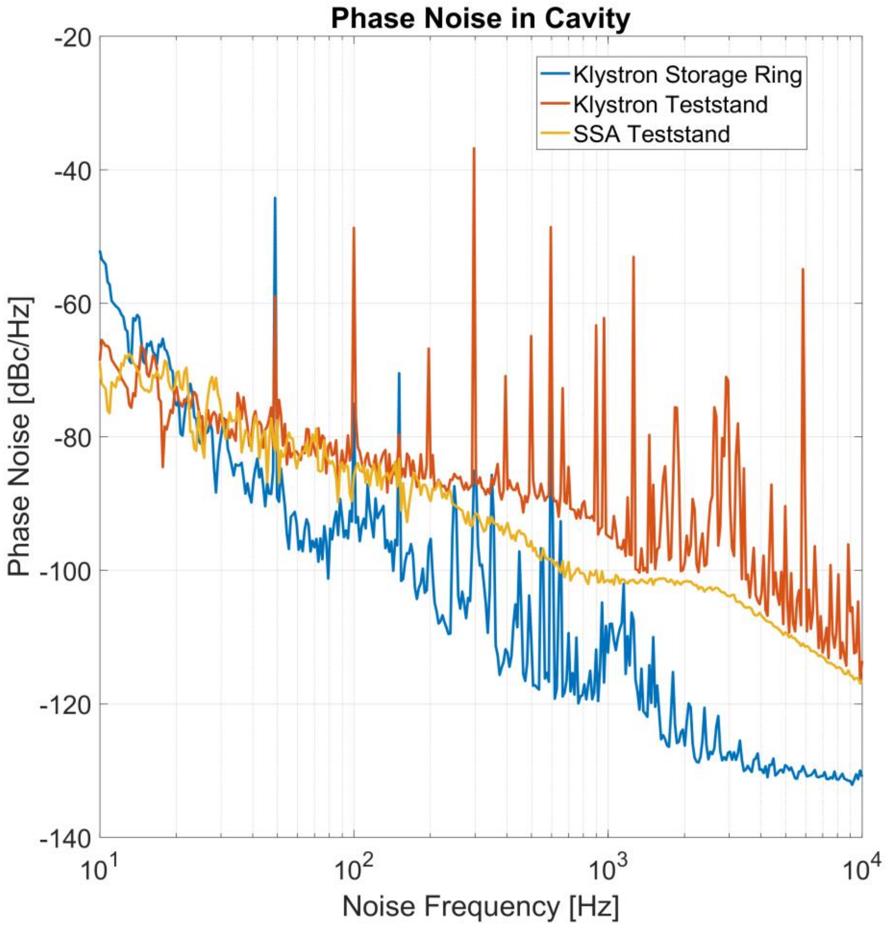
Analytical model of phase noise propagation based on Laplace transform

- SLS2 is more subseptible to low frequency noise
- SLS2 phase noise < 0.02° (SLS1: < 0.5°)
- SLS2 Klystron PS noise < 0.82V

Numerical simulation of phase noise propagation with PELEGANT

☐ To be done: Simulation of passive harmonic cavity case and gap in filling pattern

Preliminary noise measurements: Comparison of Klystron- and Solid State Amplifier



- Teststand Klystron supply operates **with** Pulse Step Modulation

- Storage Ring Klystron supply operates **without** Pulse Step Modulation

SLS2 Provisional Z-budget: Coherent Synchrotron Radiation (CSR)

SLS-2 parameters , June 2018

Circumference [m]	290.4
Betatron tunes	38.2 / 14.3
Chromaticities x/y	–99.8 / –33.0
Momentum compaction	$-1.28 \cdot 10^{-4}$
Horiz. damping partition Jx	1.765
Energy [GeV]	2.4
Radiated energy/turn [keV]	530
Emittance [pm.rad] (no IBS)	99
Natural energy spread	$1.03 \cdot 10^{-3}$
Damping times x / y / E [ms]	5.0 / 8.8 / 7.1

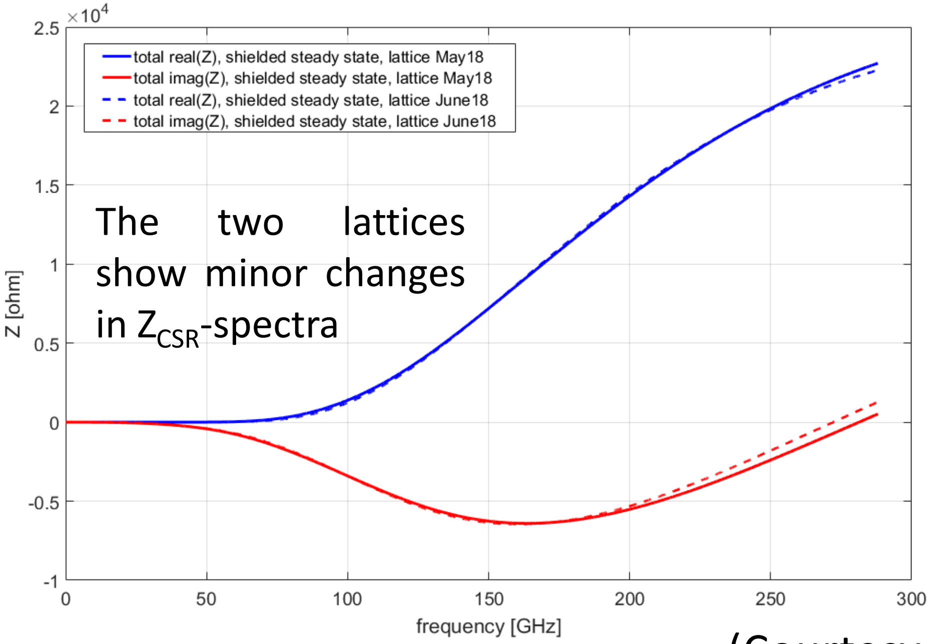
$\alpha = -1.33*10^{-04}$

SLS-2 lattice,
May 2018

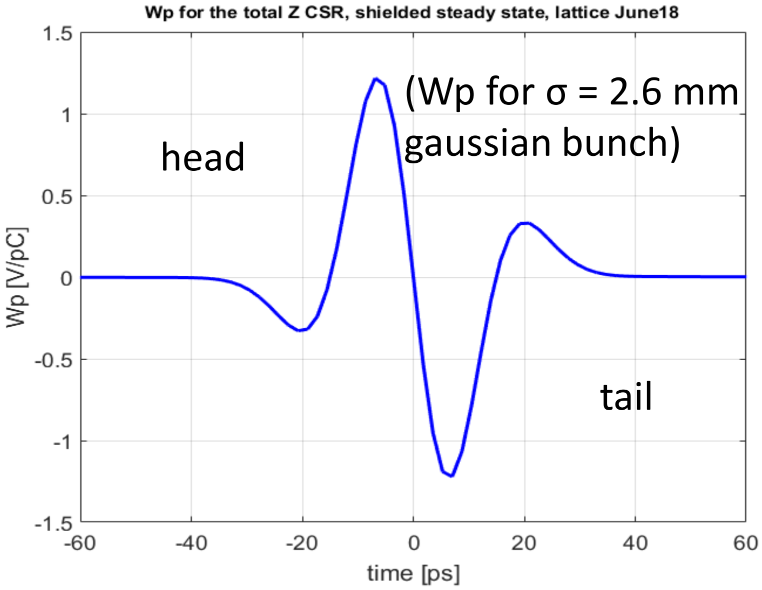
τ (s) = $6.5*10^{-03}$

SLS-2 magnet list, lattice May18:

BN = Normal Bend
L_{tot} = 37.8 m, R_{min} = 4 m, R_{max} = 11.08 m
BS = Super Bend
L_{tot} = 1.2 m, R_{min} = 1.45 m, R_{max} = 8.5 m
VB/VBM/VBS = Vertical focusing Bend
L_{tot} = 29.68 m, R = 11.66 m
AN/ANM/ANS = reversed bend
L_{tot} = 43.2 m, R = 24.55 m
Beam pipe diameter : 20 mm



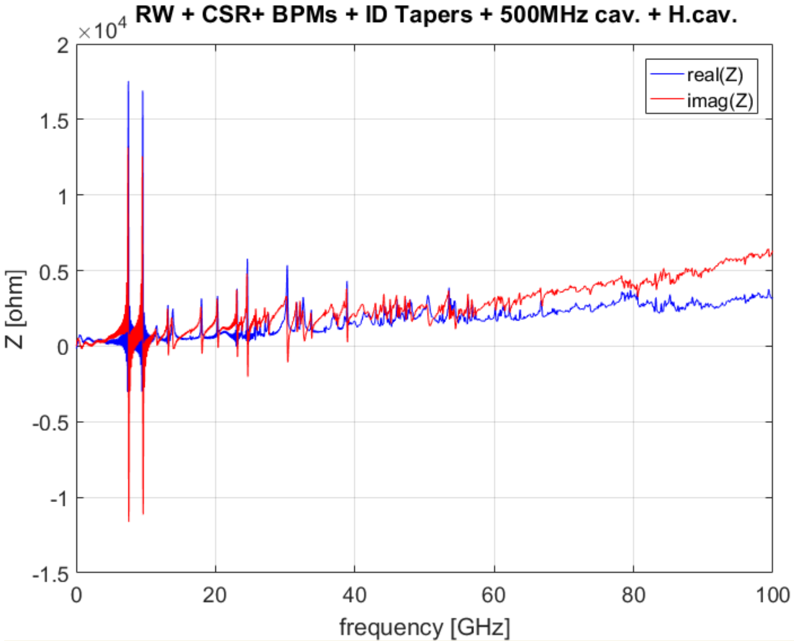
The two lattices show minor changes in Z_{CSR}-spectra

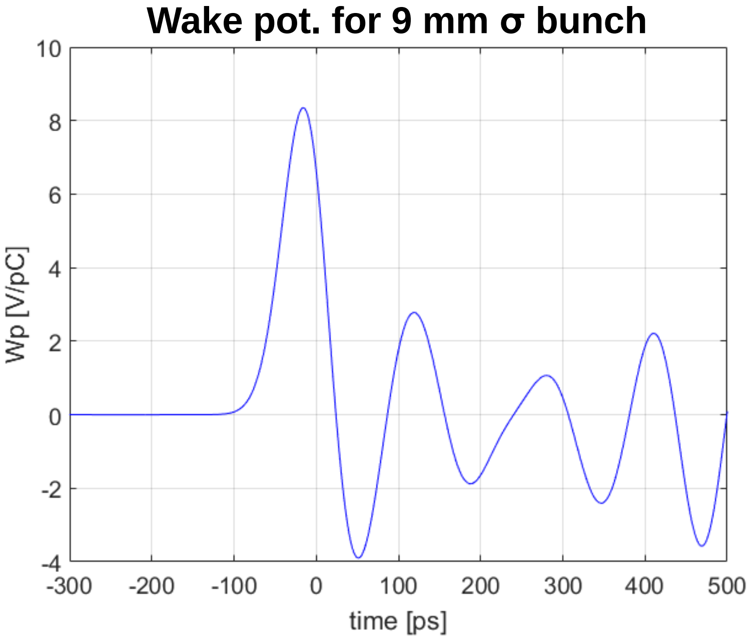


(Wp for σ = 2.6 mm gaussian bunch)

(Courtesy of A. Citterio)

SLS2: The existing Z-budget we have……





…what we have:

1. Round cross section of Ø20mm, total length 290.4m–14m–28m NEG-coated copper
2. Two kind of IDs with NEG coated copper:
   ID1: Ø 4mm,total length of 14m
   ID2: Ø 6mm, total length of 28m
3. Thickness of NEG = 500 nm.
   Assumed conductivity: σ = 1.1E6 [S/m]

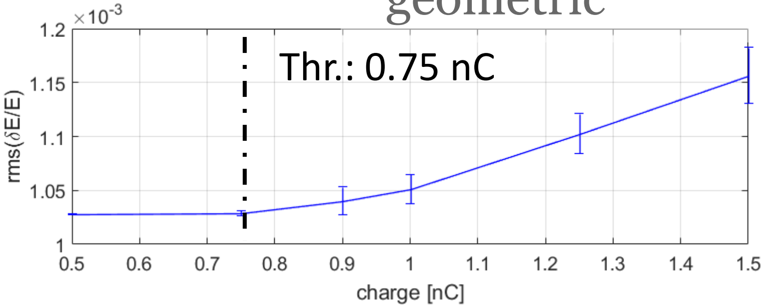
….and what we have to add:

1. Any other transition (taper), photon channels not taken into account so far,
2. Kickers, septa, MBF kickers
3. Bellows,
4. Any additional ID…
5. Design optimization of the existing Z-budget

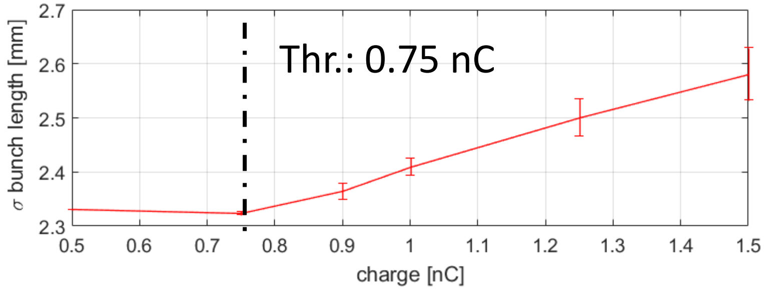
(Courtesy of A. Citterio)

SLS2 Logitudinal MW Instabilities: no HC

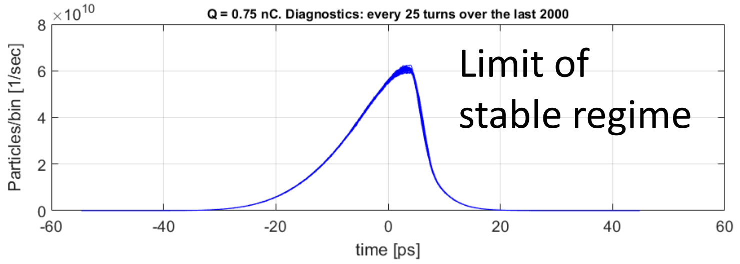
$Z_{\mathrm{geometric}}$ + RW + $\mathrm{CSR}_{\mathrm{(shielded\ s.s.)}}$



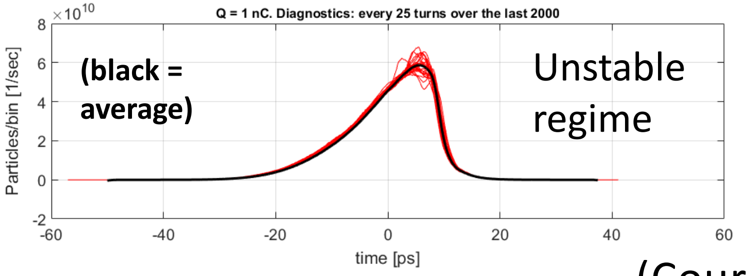
Thr.: 0.75 nC



Thr.: 0.75 nC

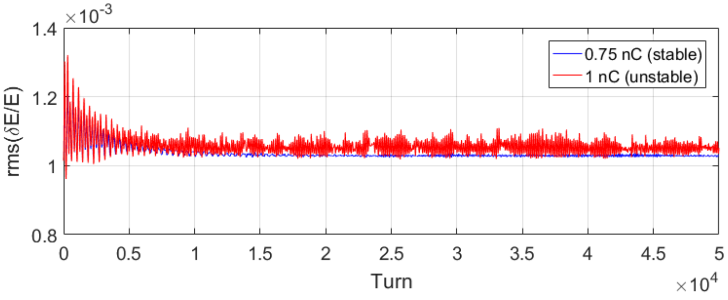


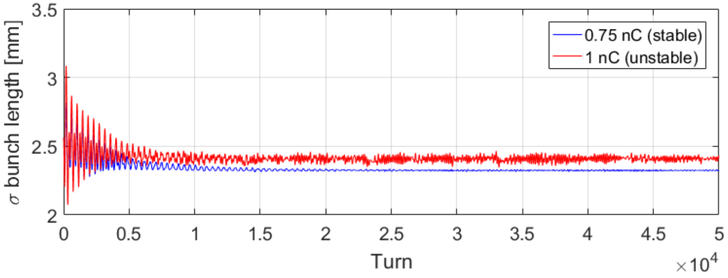
Limit of stable regime



(black = average)

Unstable regime





ELEGANT settings: **single bunch**, 8E8 MP, Z- spectrum up to 300 GHz.

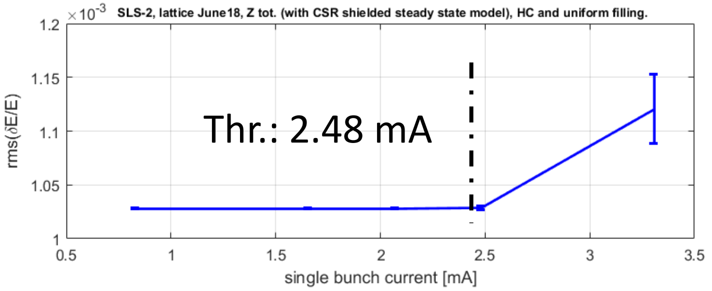
Lattice: June 2018 (latest update).

Harmonic Cavity : OFF.

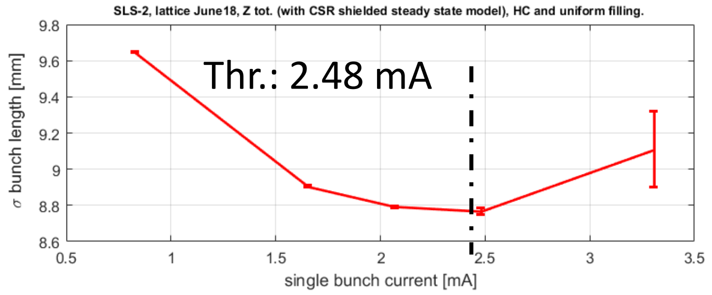
Threshold without Harmonic Cav.: 0.75 nC (< 1 nC op. charge !)

(Courtesy of A. Citterio)

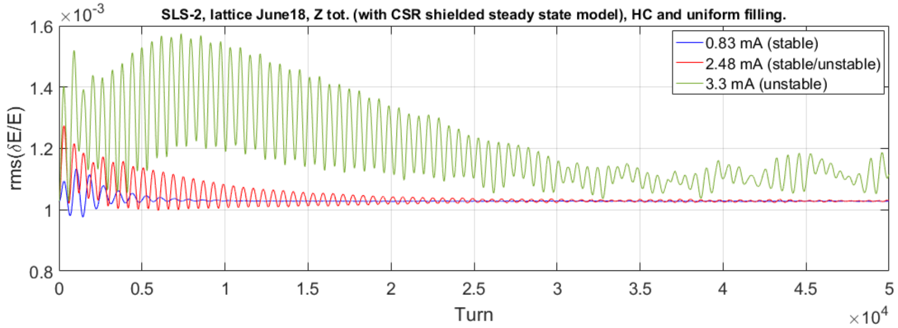
SLS2 Logitudinal MW Instabilities: with 3HC $Z_{geometric}$ + RW + $CSR_{(shielded\ s.s.)}$



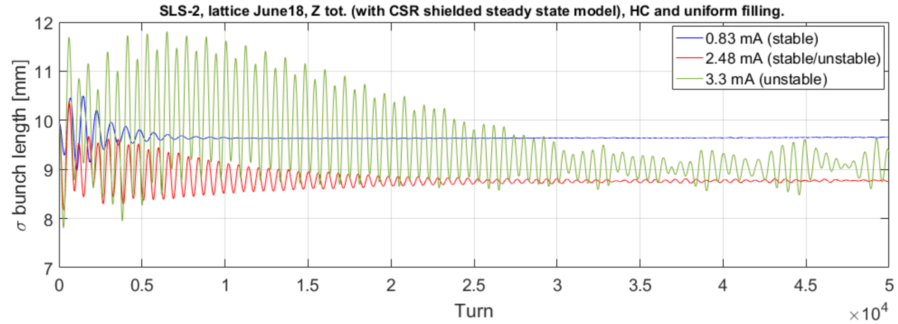
SLS-2, lattice June18, Z tot. (with CSR shielded steady state model), HC and uniform filling.



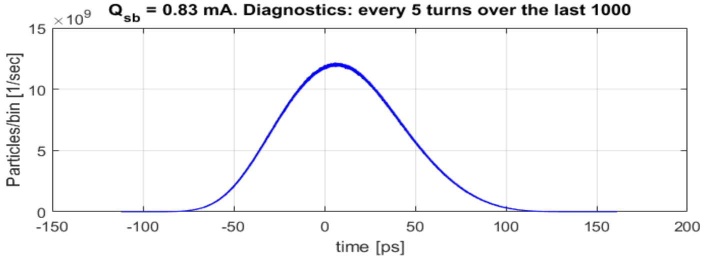
SLS-2, lattice June18, Z tot. (with CSR shielded steady state model), HC and uniform filling.



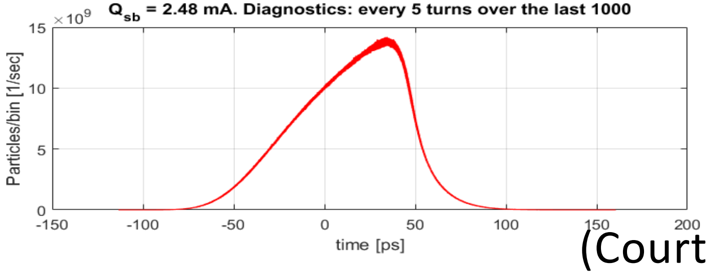
SLS-2, lattice June18, Z tot. (with CSR shielded steady state model), HC and uniform filling.



SLS-2, lattice June18, Z tot. (with CSR shielded steady state model), HC and uniform filling.



Q_{sb} = 0.83 mA. Diagnostics: every 5 turns over the last 1000



Q_{sb} = 2.48 mA. Diagnostics: every 5 turns over the last 1000

Super-3HC : ON, with only 1 cell.

500 MHz Cav. setting: 3 Cav

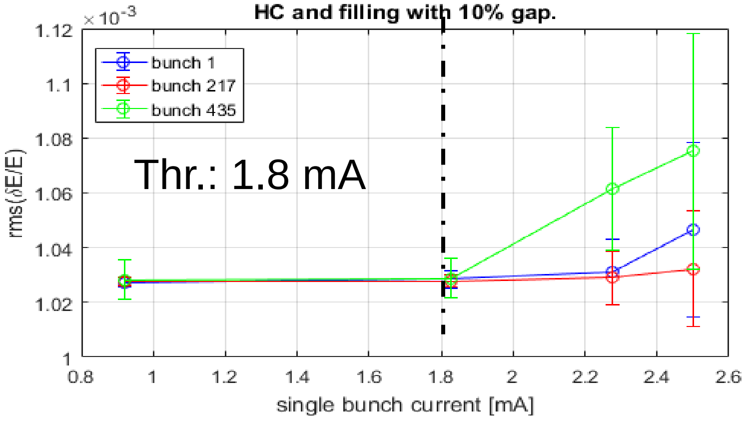
Current tested: 400 mA, **but** with f*Z_{tot} (with f= 1, 2 ,2.5 ,3 ,4).

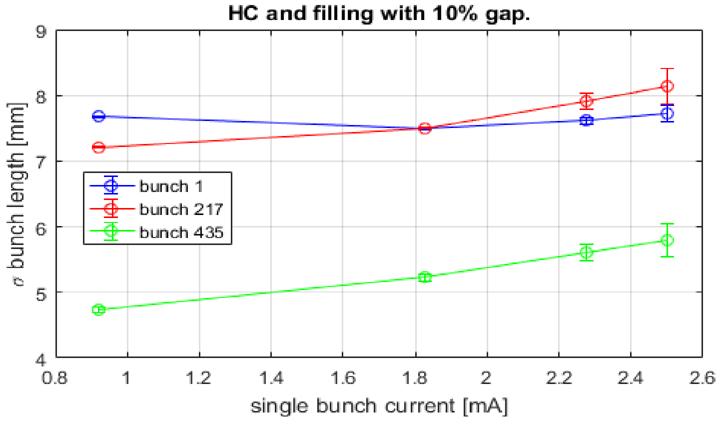
Expected safety threshold with uniform filling looks guaranteed within a factor 3, or I_{sb} = 2.48 mA.

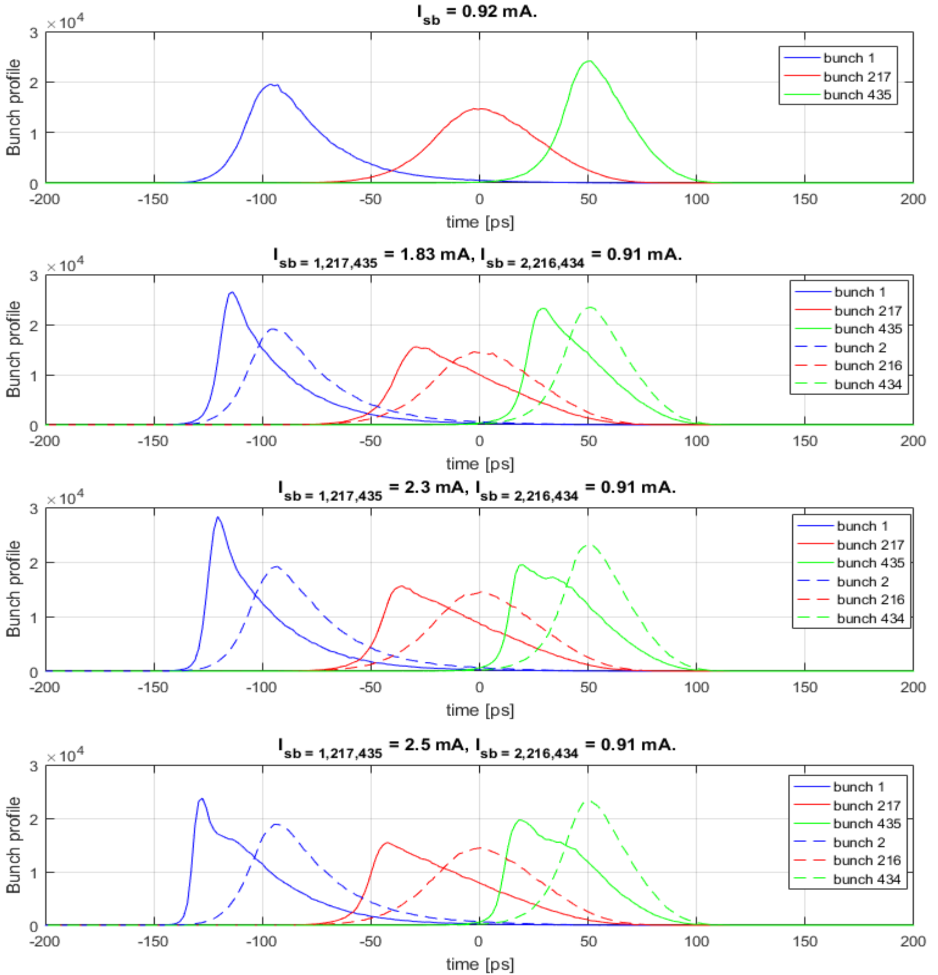
The gap in filling pattern will reduce the margin.

(Courtesy of A. Citterio)

SLS2 Logitudinal MW Instabilities: 3HC and gap
$Z_{\text{geometric}}$ + RW + $\text{CSR}_{(\text{shielded s.s.})}$







Mbtrack settings: **multibunch**, 5E5 MP/bunch, Z modeled with $W_f(t)$ and L,

10% gap filling pattern → 400 mA ≡ 0.9 mA sb

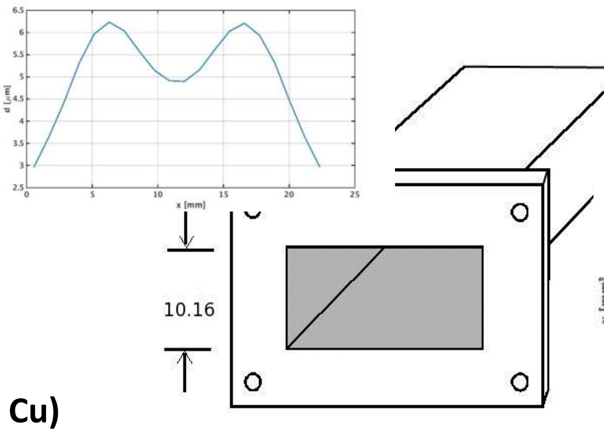
Current tested: bunches n. 1/217/435 up to 2.5 mA, others at 0.9 mA

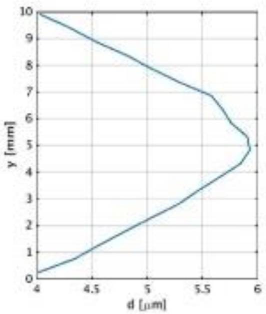
Preliminary threshold with 10% gap filling pattern: I_{sb} = 1.8 mA.

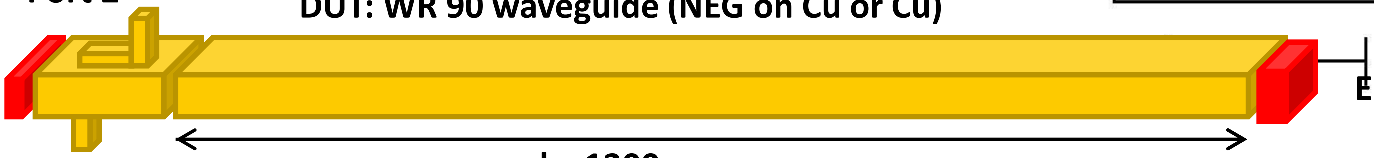
(Courtesy of A. Citterio)

SLS2: Characterization of RF properties of NEG coatings for SLS2 (on going process…)

X-band waveguide with length: 1300 mm
1100 mm with average thickness of 5.1 um
200 mm length with avg. thickness 3.1 um
Process gives also systematic transverse thickness variations, theoretical profiles as calculated with MOLFLOW shown in the figure



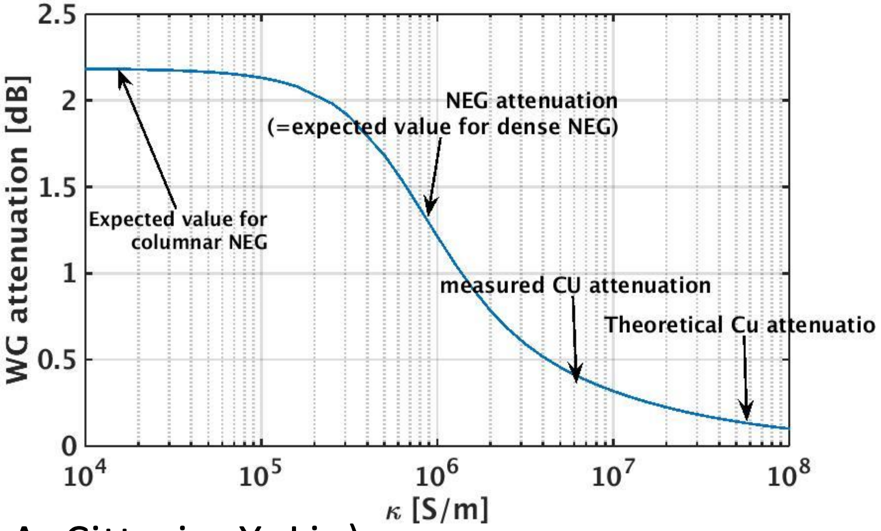




Double short the waveguide to create resonator
30 dB directional coupler to measure resonances

Insertion loss of waveguide shows up in width of the resonances/Q factors

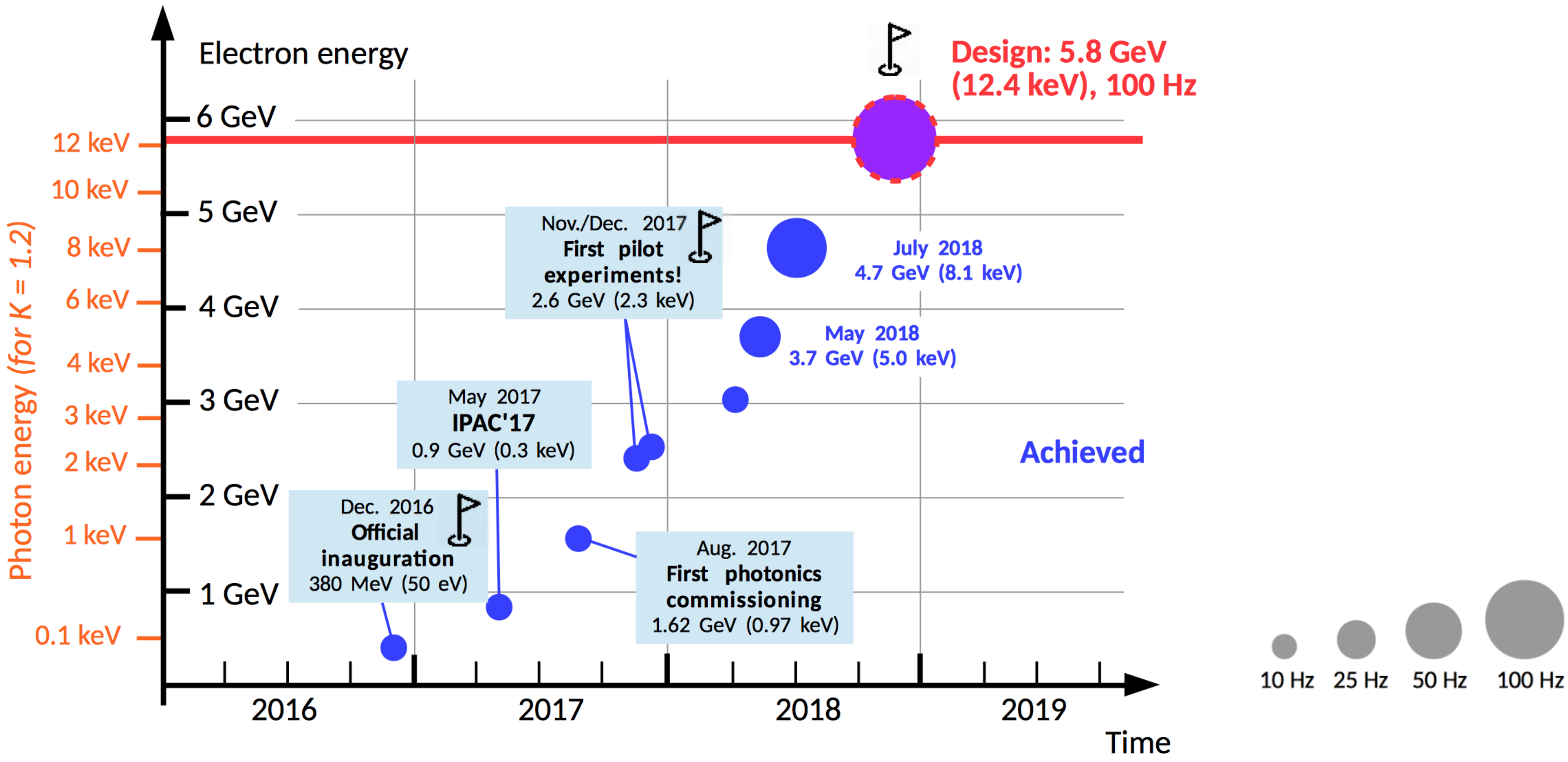
Use measured scattering parameter model of setup (modelled in Matlab) to fit resonance Q factor to insertion loss and to NEG conductivity



Big advantage of approach: Don't rely on comparison between Cu and NEG, but do direct measurement!

(Courtesy of M. Dehler, A. Citterio, X. Liu)

SwissFEL Machine Evolution



(Courtesy of P. Craievich and SwissFEL team)

Outlook Athos (soft-X-ray line)

Athos schedule:

Athos dogleg ready for commissioning since June 2018

U38 module prototype delivered in June 2018

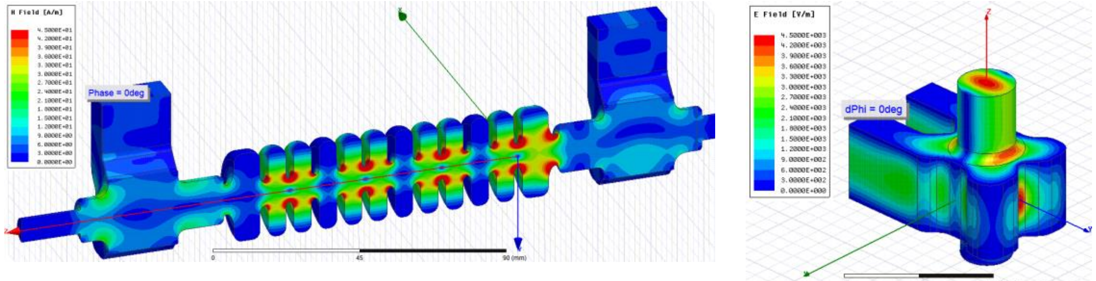
Delay chicanes in procurement

Undulator installation Jan. 2019 – March 2020

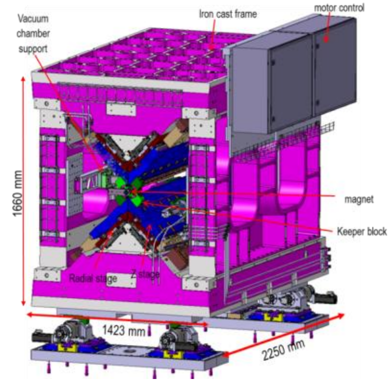
First pilot experiment end 2020

User operation from 2021

Post-undulator X-band TDS with variable polarization



Collaboration between CERN, DESY and PSI



- Redesigned soft-X-ray undulator line featuring 16 **Apple-X U38** undulators:
  - full polarization control
  - independent K and polarization control
  - transverse gradient undulator (TGU)
  - symmetric force distribution (gap = slit)
- Small **interundulator magnetic chicanes** to enable
  - Optical klystron mode
  - High-brightness mode
  - Terawatt-attosecond mode
- One large **magnetic chicane** for two-color operation (delay between −10 fs and +500 fs)

(Courtesy of P. Craievich and SwissFEL team)

Thank you for your attention!

We thank

- Ryutaro Nagaoka and Francis Cullinan for their support on the mbtrack code.
- ESRF for coating of the X-band waveguide
- KEK (D. Zhou) for providing CSR-impedance and SLAC (K. Bane, C. Mayes) for discussions
- RF- and SLS2 team