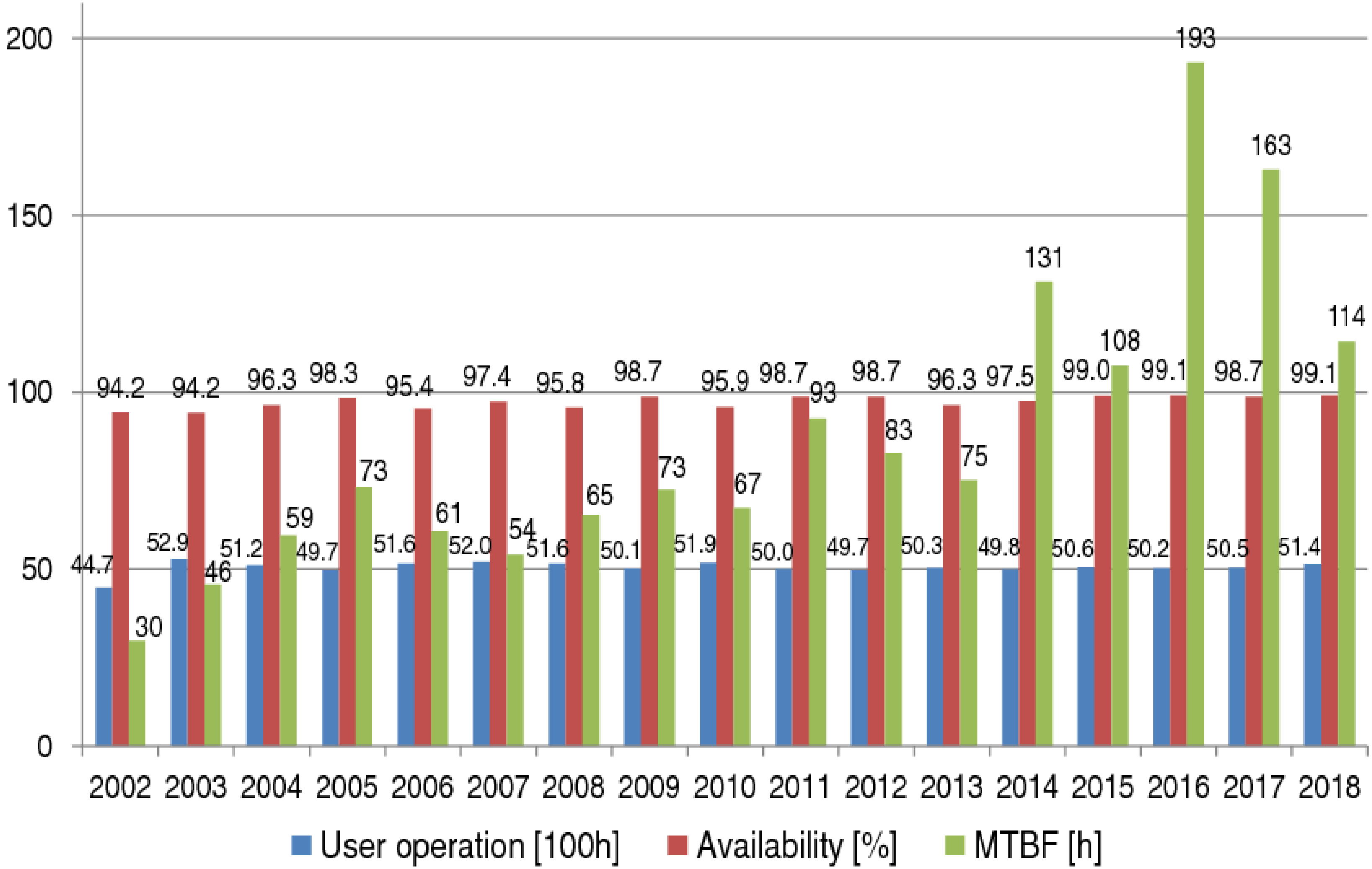
Lukas Stingelin :: Group RF Systems 1 :: Paul Scherrer Institut

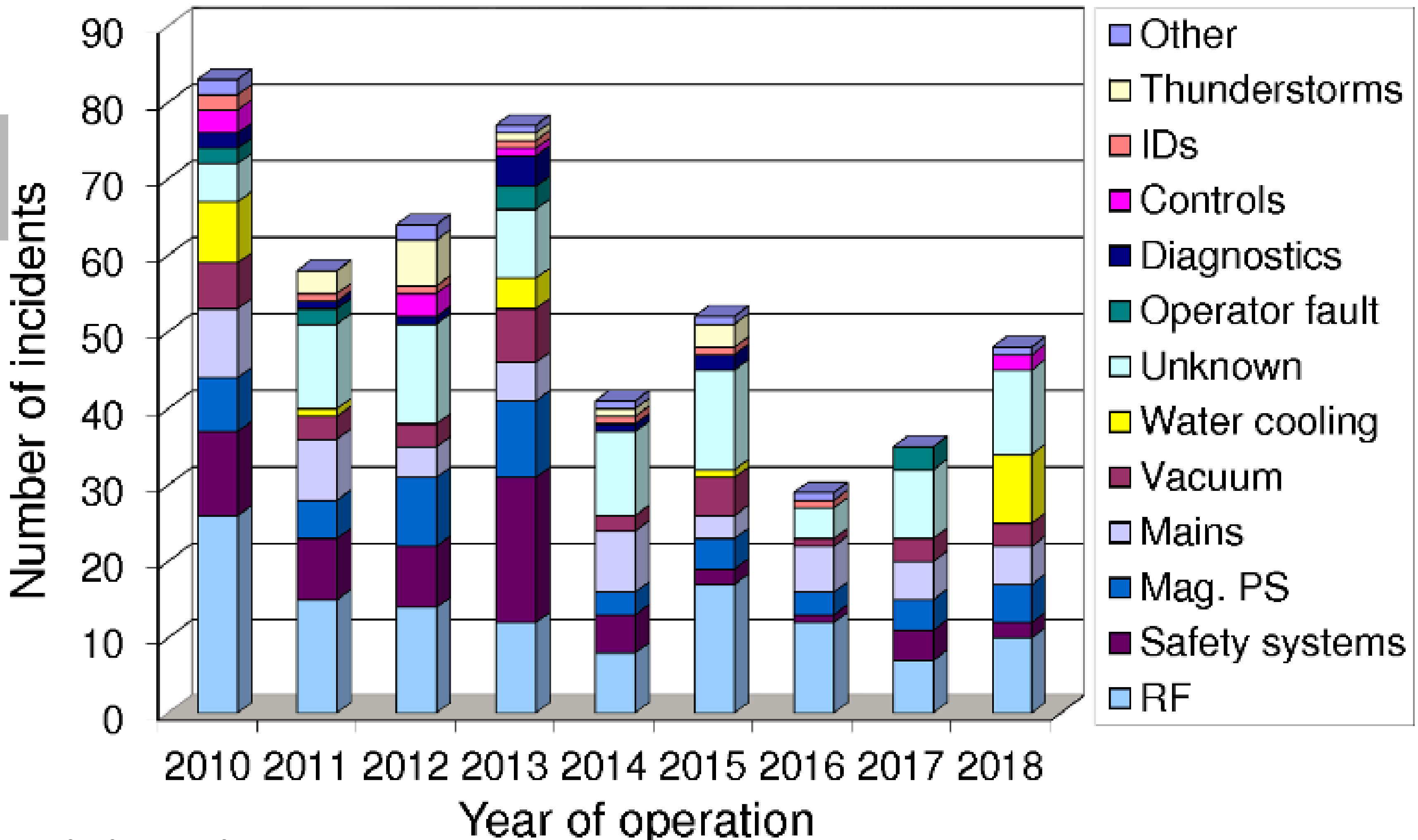
SLS RF operation and status of the SLS-2 project

23rd ESLS-RF workshop, from 24th to 25th of October 2019,
Diamond Light Source, Didcot, Oxfordshire, OX11 0DE, United Kingdom

SLS Operation Statistics



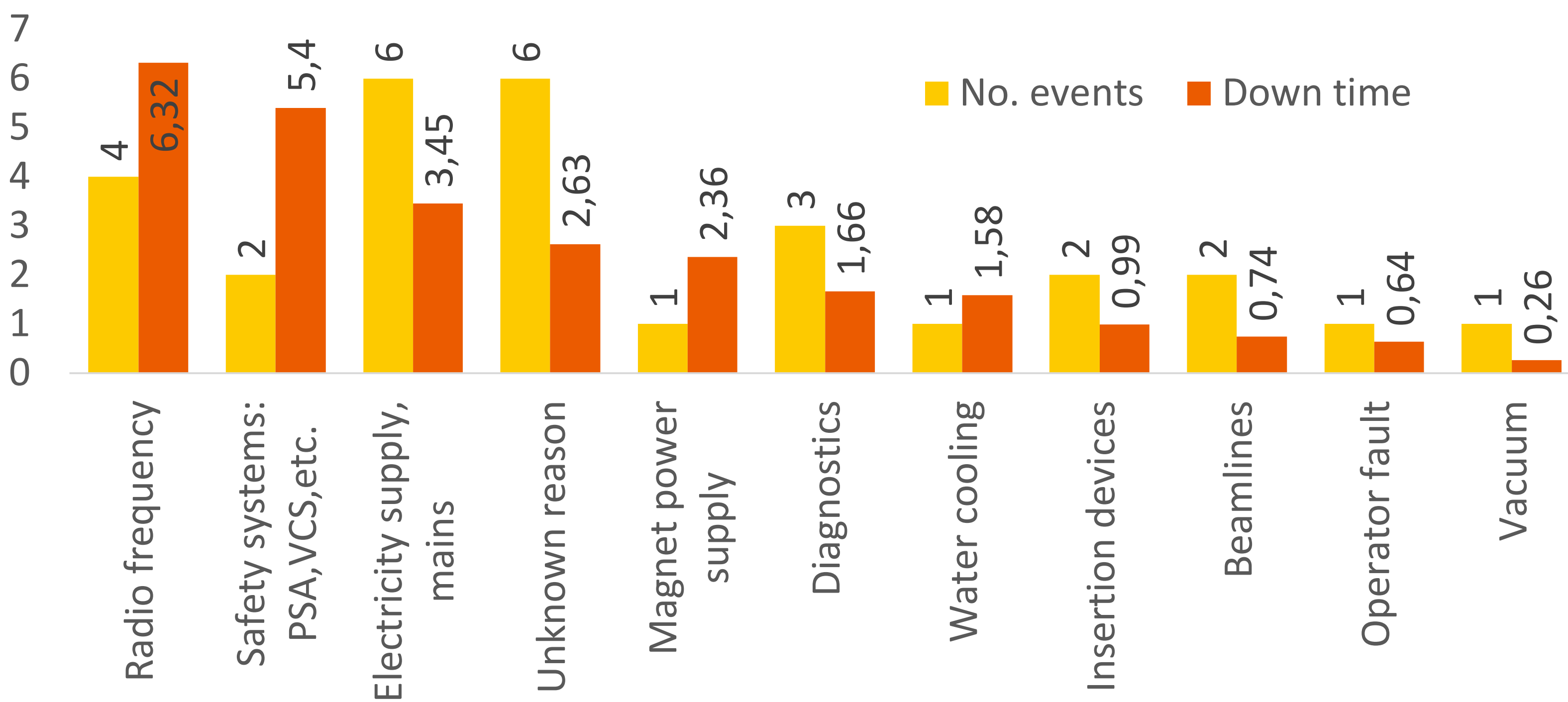
Beam Outage Count per System



Main issues in 2018:

- Water flow regulation → heads of needle valves fixed
- Klystron vacuum pumps current interlocks → hi-potting
- Loose contact in temperature measurement

Operation Statistics 1.1. until 19.10.2019



Events caused by RF:

1. AMLP interlock
2. Super-3HC Cryosystem failure
3. AMLP interlock
4. Klystron Focus PS failure

SLS RF works

Done:

- ✓ LINAC isolation Oil treatement system
- ✓ Storage-Ring: Klystron optimization
- ✓ Super-3HC: Controls interface

In Progress:

- □ LINAC pulser board upgrade to shorter bunches
- □ LINAC LLRF-upgrade → «SwissFEL»
- □ Storage-Ring: HOMFS upgrade
- □ Storage-Ring: LLRF upgrade
- □ Storage-Ring: HOM-absorber investigation
- □ Refurbishment of 500MHz Klystrons from Daresbury
- □ Apply for Energy Efficiency Funding (ProkW) and Procurement of 500MHz solid state power amplifier

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SLS HOMFS upgrade

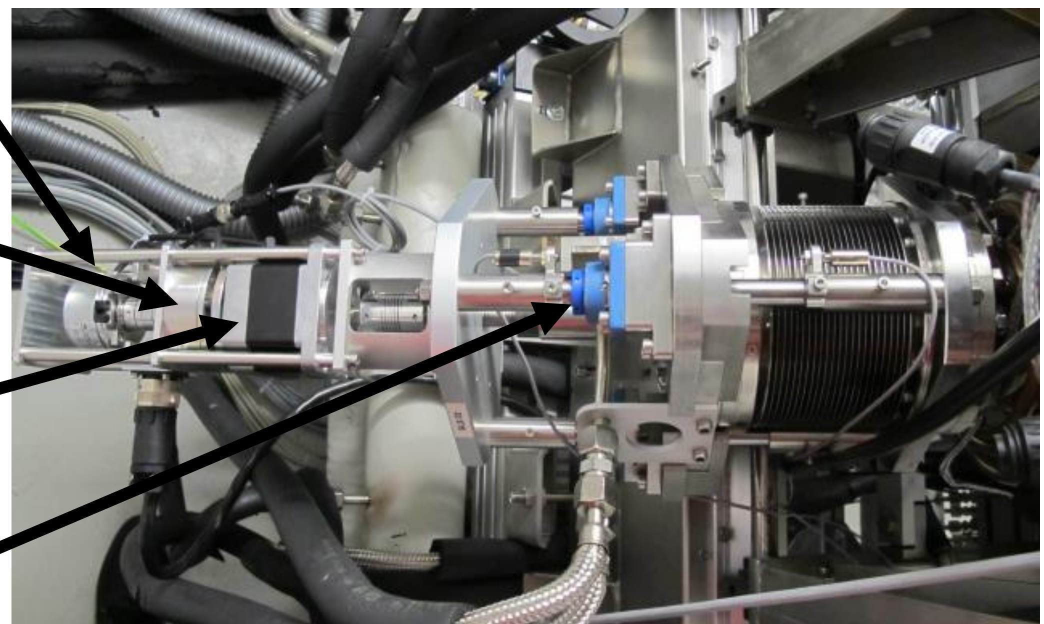
New stepping motor driver and brake-controller

Encoder

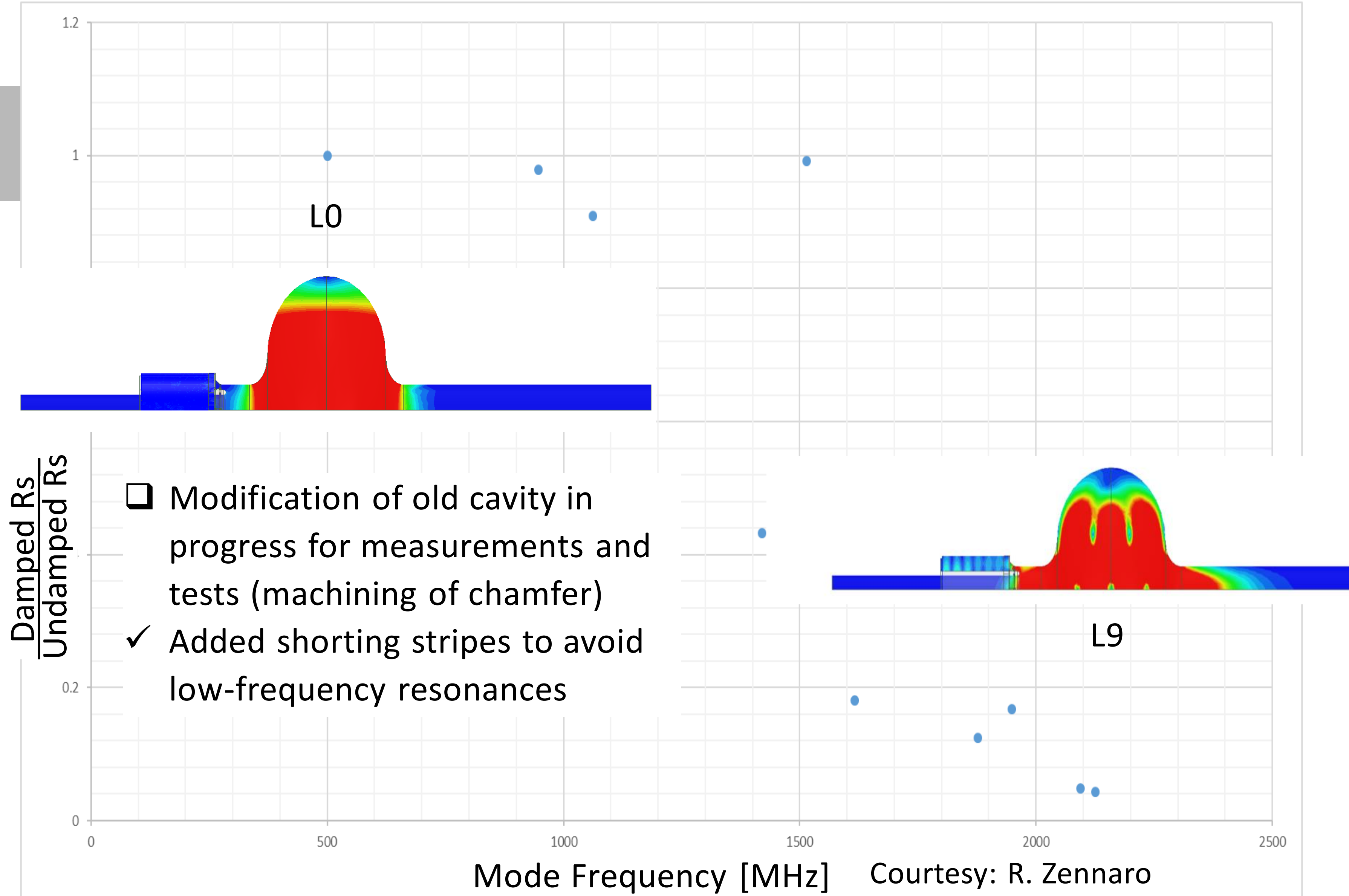
Brake

Stepping motor

Bearing

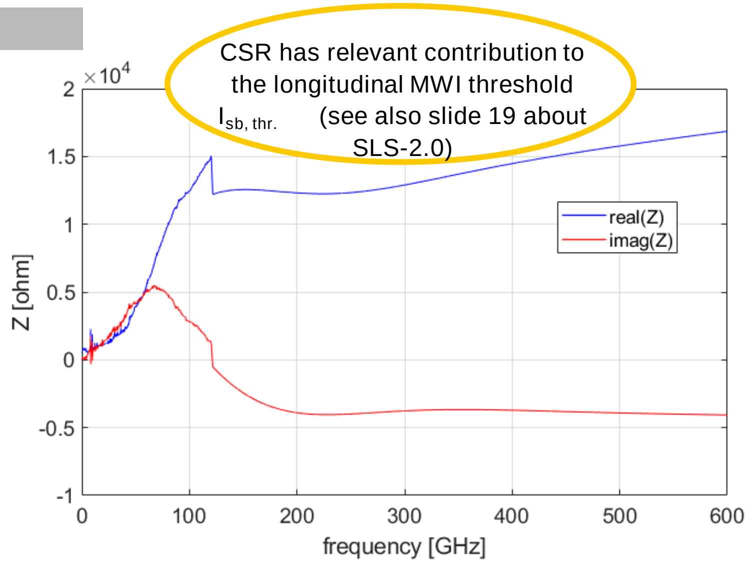


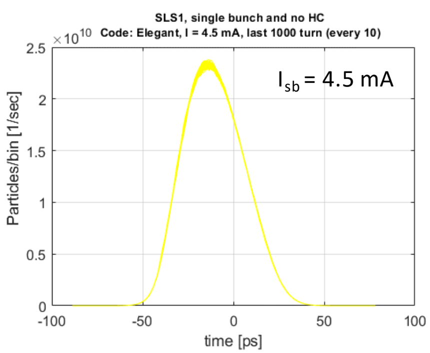
L9 HOM Damper

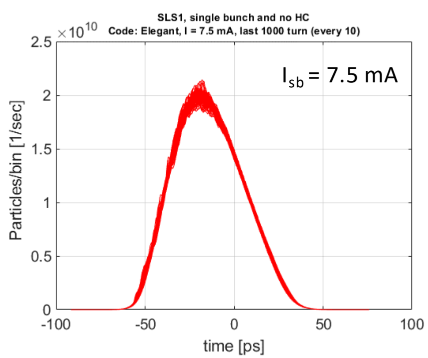


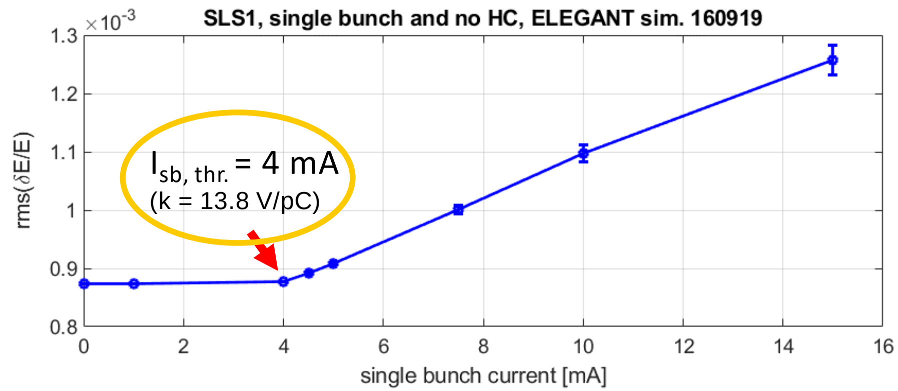
- ❑ Modification of old cavity in progress for measurements and tests (machining of chamfer)
- ✓ Added shorting stripes to avoid low-frequency resonances

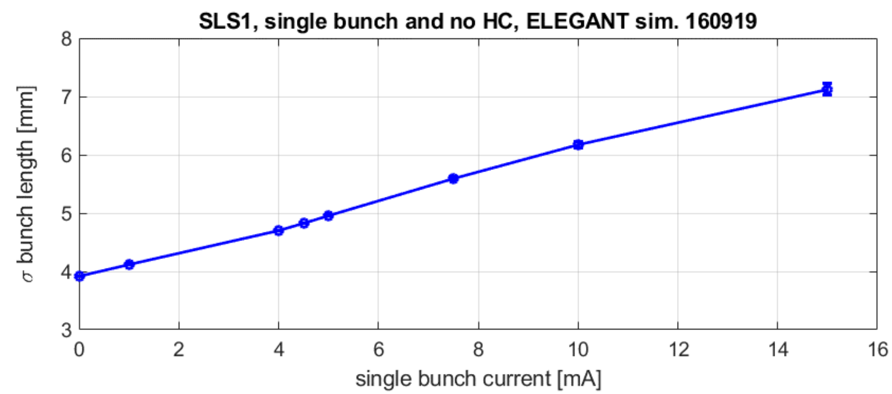
Impedance- and Threshold Calculation for SLS





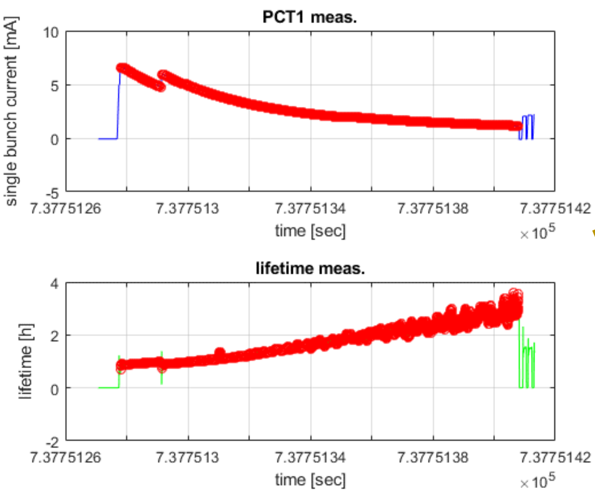






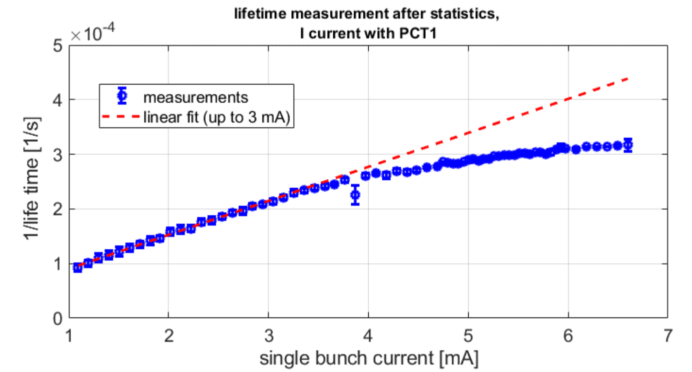
Courtesy: A. Citterio

SLS Threshold Measurements



Strategy: Touschek lifetime scales linearly with the bunch length. If a deviation is due to a turbulent lengthening of the bunch:

Observation of lifetime for high single bunch currents may provide information on bunch lengthening thresholds and the impedance involved.

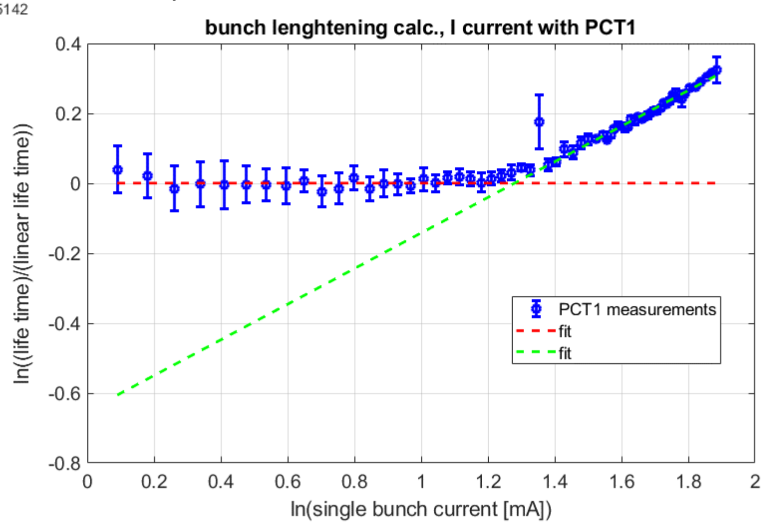


Turbulent Bunch Lengthening Equation (for $I > I_{b,thr.}$):

$$\ln x = \underbrace{A \ln\left(K \left|\frac{Z_{\parallel}}{n}\right|_o^{\mathrm{bb}}\right)}_{B} + A \ln I_b$$

x = bunch lengthening parameter (ratio of Touscheck lifetime to linear fitted lifetime)

I_b = single bunch current



Longitudinal single bunch MicroWave Instability Threshold*:

# shift	PCT1 $I_{thr.}$ [mA]	PCT2 $I_{thr.}$ [mA]
10/09/19	3.5	3.9
01/10/19	3.3	3.2
15/10/19	3.7	4.2
22/10/19	3.6	3.7

*post-processing data still on going

Courtesy: A. Citterio

SLS2 new lattice parameters

	SLS 2 (lattice b038) Phase-1	SLS 2.1 (b138) Phase-2	SLS
Circumference [m]	288.000177	288.000256	288.0007289
Energy [GeV]	2.4	2.4	2.4
Emittance [pm rad]	123	128	5579
Lattice energy loss/turn [keV]	432	441	539
IDs max. energy loss/turn [keV]	232.5	232.5	60
Energy spread	$1.016*10^{-3}$	$1.053*10^{-3}$	$0.874*10^{-3}$
Momentum compaction α_c	$+1.02*10^{-4}$	$+1.02*10^{-4}$	$+6.04*10^{-4}$
Energy acceptance (without 3HC)	0.03	0.03	0.03
Main RF frequency [MHz]	499.6	499.6	499.6
Total main RF voltage nominal [kV] (3% momentum acceptance)	980	980	2080
Total main RF voltage maximum [kV]	1100	1100	2600
Harmonic number	480	480	480
Gap in the filling pattern	4.2%	4.2%	19%

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SLS2 RF Parameters

normal case: 2 cavities operational

	SLS 2
Max. Energy loss/turn	674keV
Momentum compaction α_c	$+1.02*10^{-4}$
Nominal:	
Total main RF voltage nominal	980kV
→ Bunch length without harmonic cavity	10.4ps
→ Energy acceptance with 3HC *	~[-5.36,+3.96]%
→ Touschek lifetime with 3HC *	~9.7 h @ 400 mA
Shunt Impedances @ room temp. [MΩ]	3.41, 3.6, 3.6, 3.4
→ min. RF Power required per RF station:	170kW
Optional (with reserve):	
Total main RF voltage maximum	1100kV
Beam loading factor	0.98
→ Bunch length without harmonic cavity	9.4ps
→ min. RF Power required per RF station:	179kW
→ Total RF Power required	358kW

→ Optimal coupling=4.8

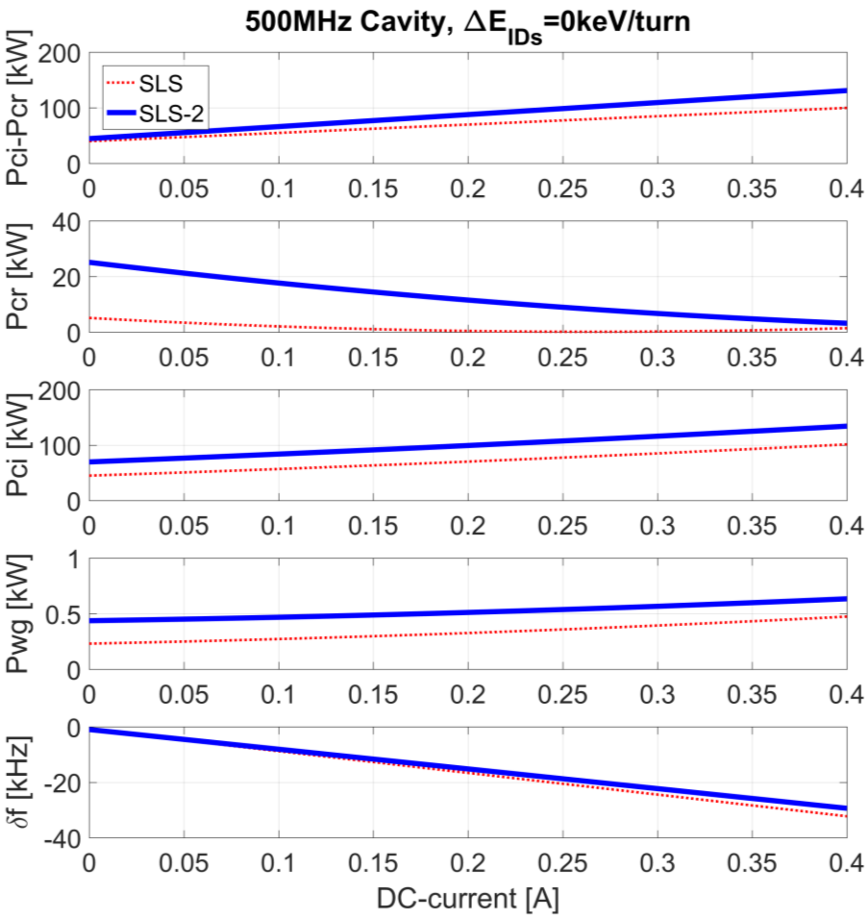
Detuning for matching: -25kHz

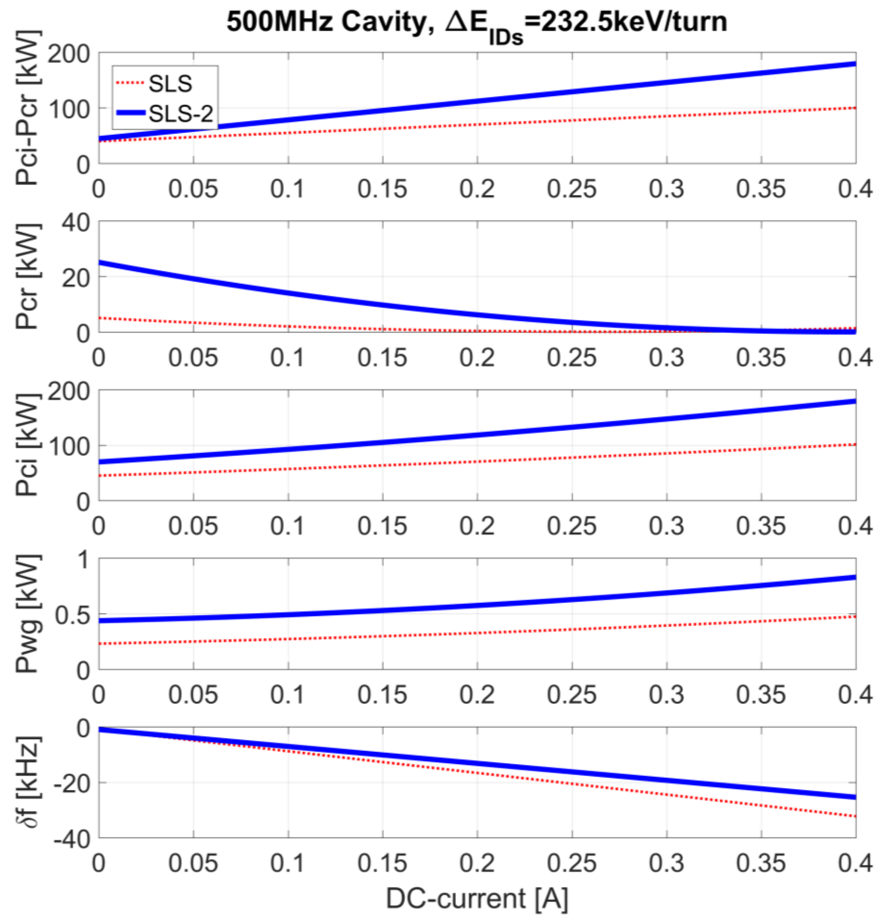
→ Optimal coupling=4.0

Detuning for matching: -24kHz

(*Energy acceptance and lifetime from A. Streun)

Power balance in function of beam current: Case of 2 main-cavities: (total 1.1MeV)





SLS2 RF Parameters

case under study: 3 cavities operational

	SLS 2
Max. Energy loss/turn	674keV
Momentum compaction α_c	$+1.02*10^{-4}$
Nominal:	
Total main RF voltage nominal	980kV
→ Bunch length without harmonic cavity	10.4ps
→ Energy acceptance with 3HC *	~[-5.36,+3.96]%
→ Touschek lifetime with 3HC *	~9.7 h @ 400 mA
Shunt Impedances @ room temp. [MΩ]	3.41, 3.6, 3.6, 3.4
→ min. RF Power required per RF station:	103kW
Optional (with reserve):	
Total main RF voltage maximum	1100kV
→ Bunch length without harmonic cavity	9.4ps
→ min. RF Power required per RF station:	110kW
→ Total RF power required	**330kW**

(*Energy acceptance and lifetime from A. Streun)

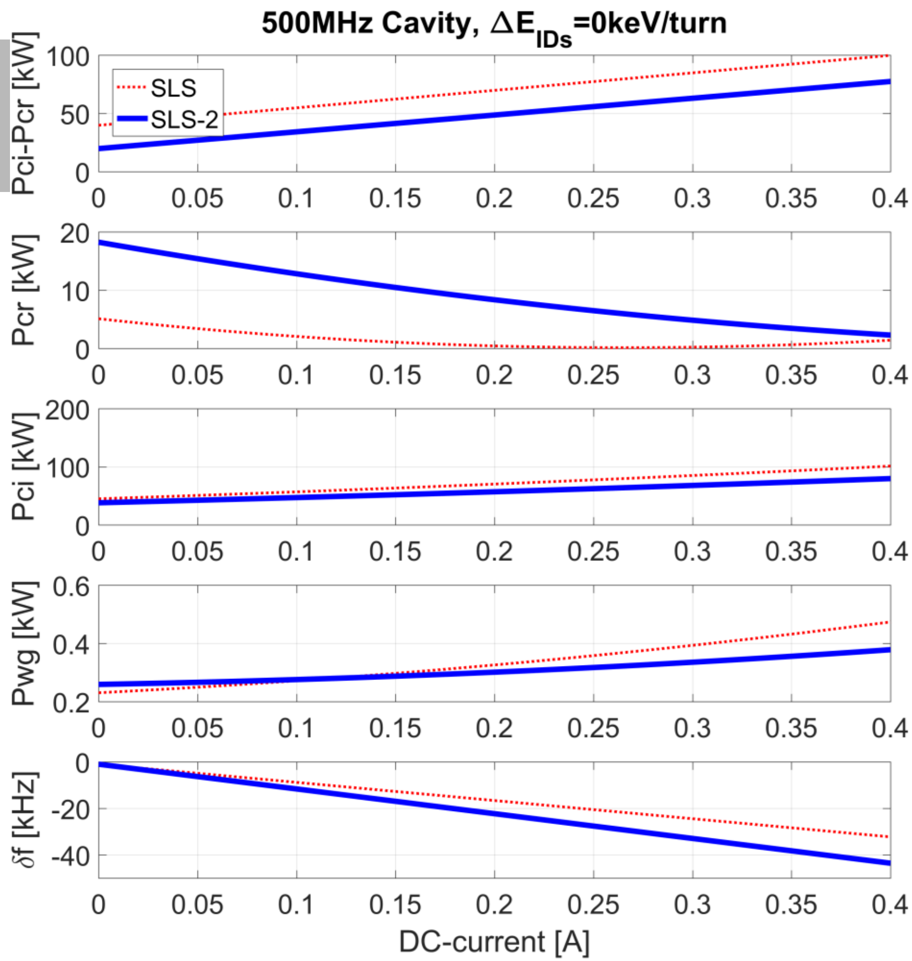
→ **Optimal coupling=7.8**

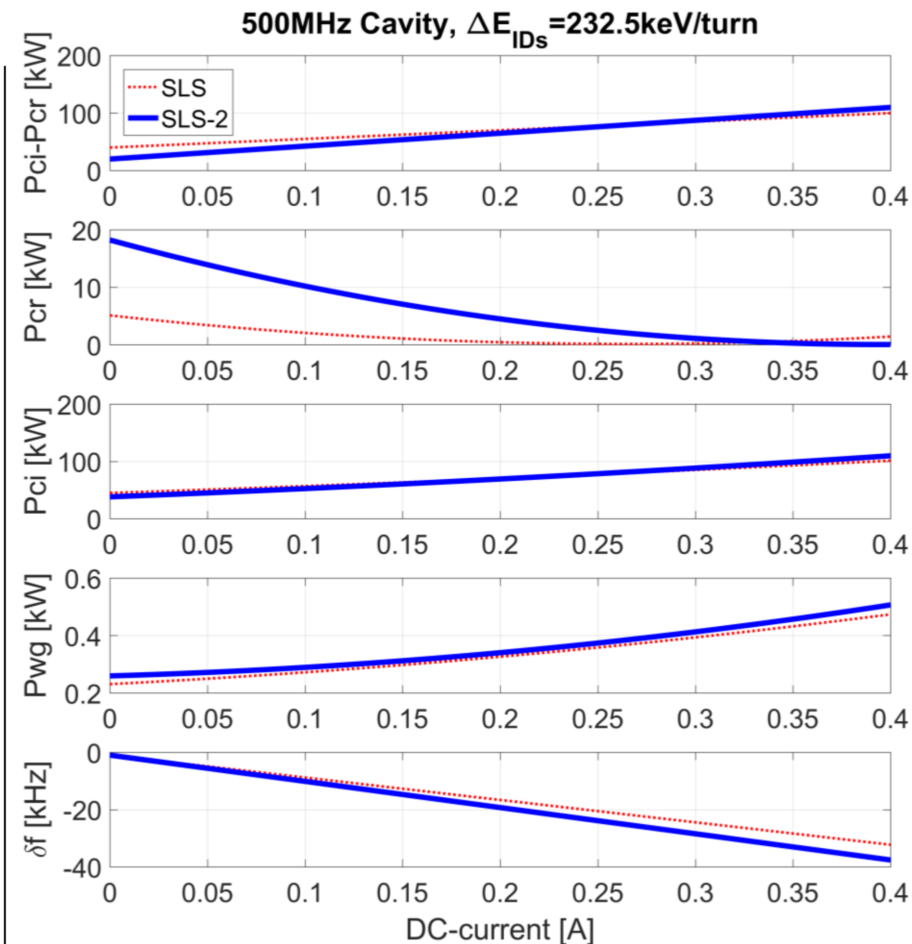
Detuning for matching: -38kHz

→ **Optimal coupling=5.5**

Detuning for matching: -37kHz

Power balance in function of beam current:
Case of 3 main-cavities: (total 1.1MeV)





SLS2 RF Parameters

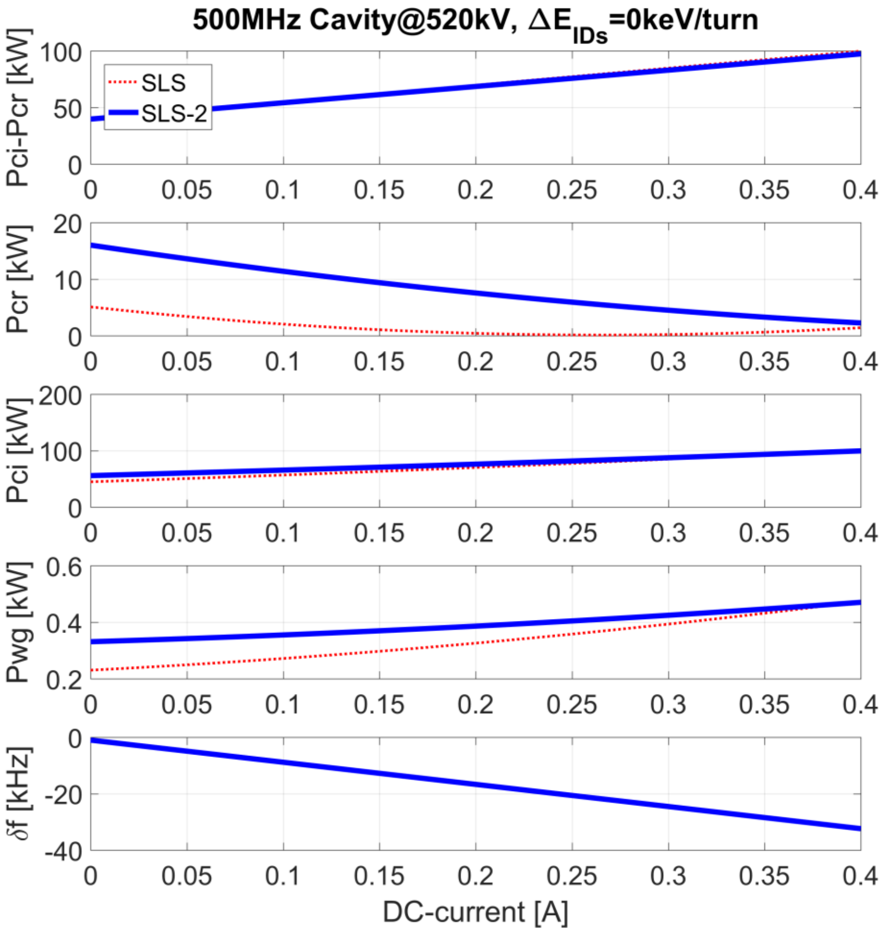
case under study: 3 cavities operational with higher voltage

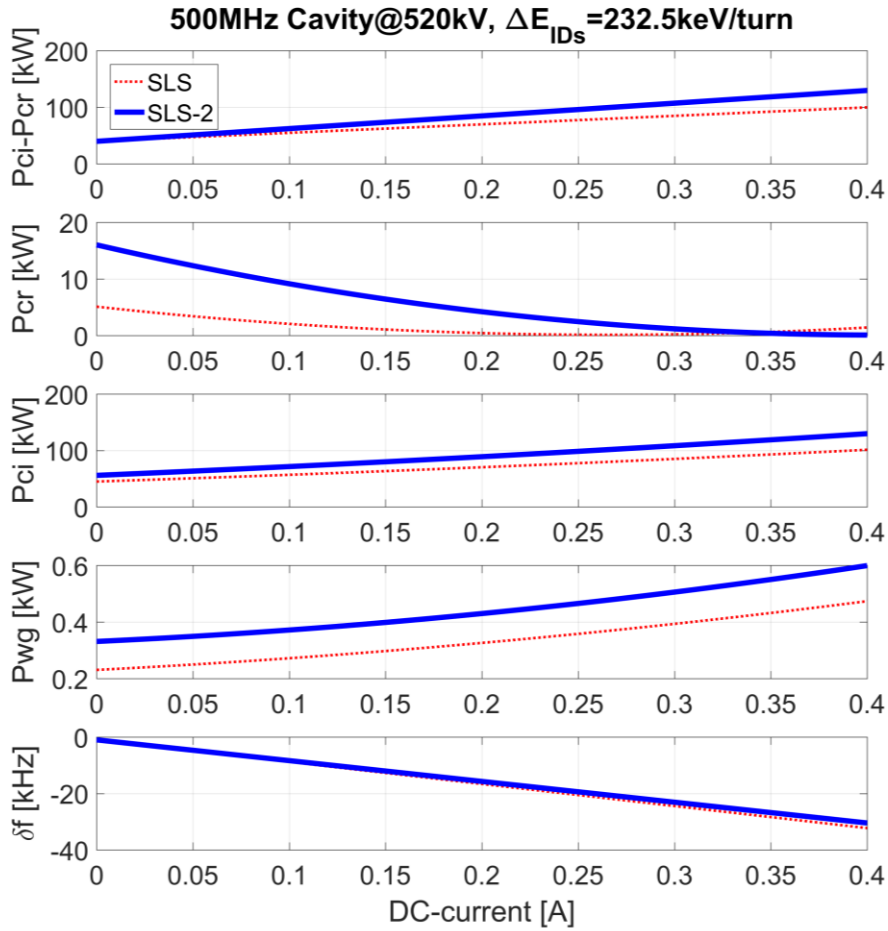
	SLS 2
Max. Energy loss/turn	674keV
Momentum compaction α_c	$+1.02*10^{-4}$
With higher voltage: (520kV/cavity)	
Total main RF voltage nominal	1560kV
→ Bunch length without harmonic cavity	**7.4ps**
Shunt Impedances @ room temp. [MΩ]	3.41, 3.6, 3.6, 3.4
Beam loading factor	**1.228**
→ min. RF Power required per RF station:	130kW
→ Total RF Power required:	**390kW**

→ Optimal coupling=3.3

Detuning for matching: -30kHz

Power balance in function of beam current: Case of 3 main-cavities: (total 1.56MeV)



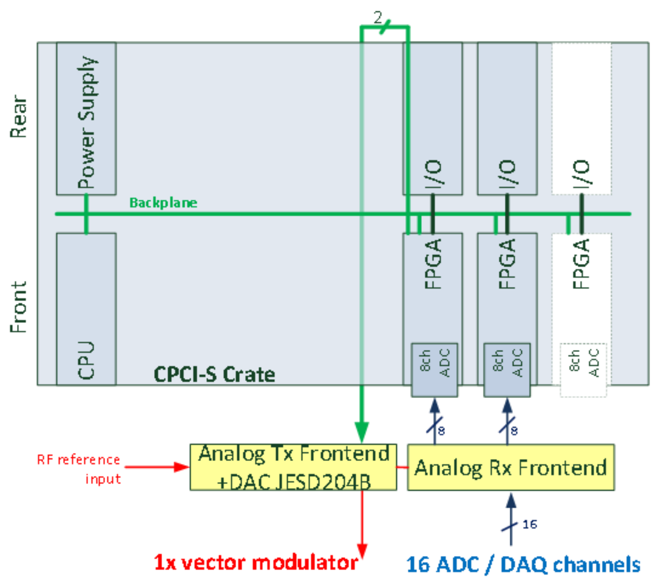


500MHz LLRF-Upgrade

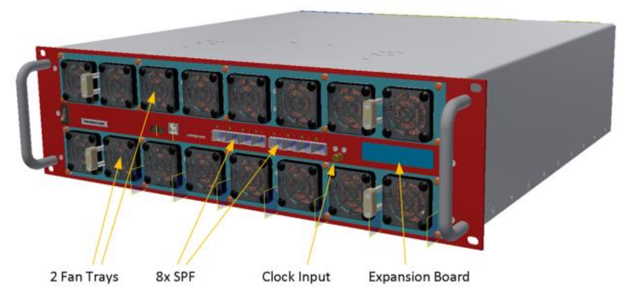
Two candidates:

CompactPCI Serial

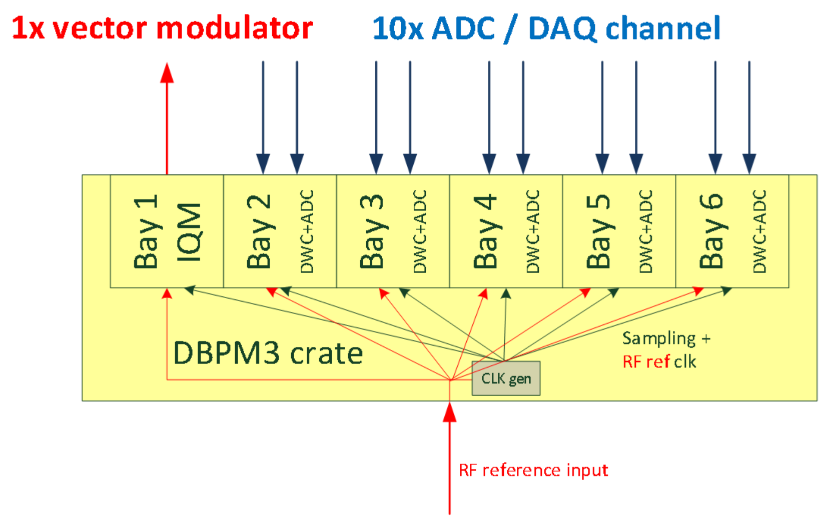
For ex. CPCI-S Crate, ADLinkTech



PSI DBPM3



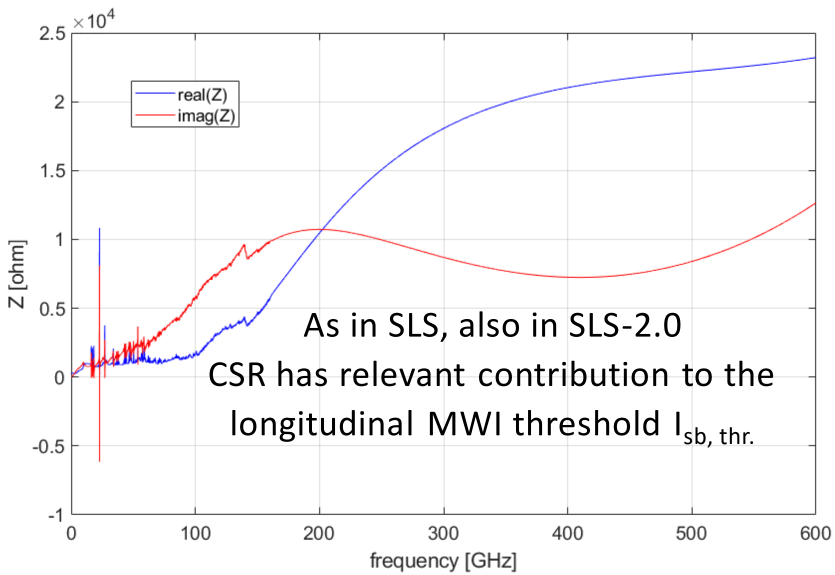
DBPM3 Crate, PSI

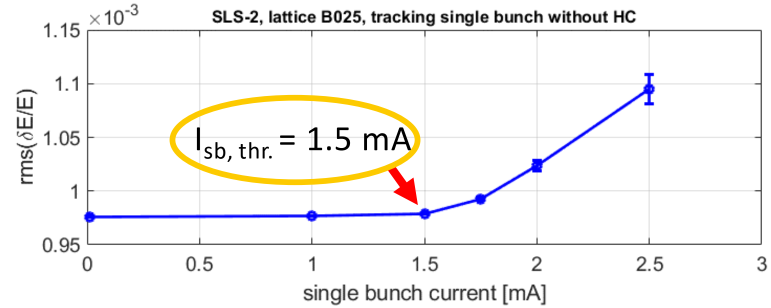


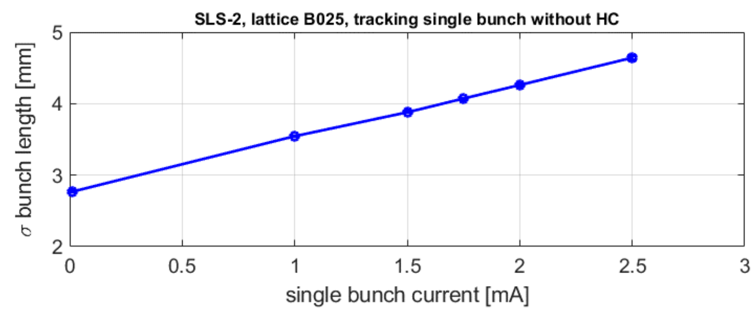
Courtesy: R. Kalt (poster at LLRF workshop 2019)

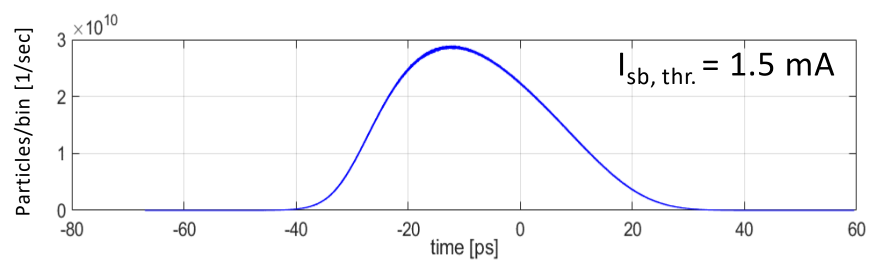
Impedance and Threshold Calculations for SLS2

SLS 2.0 parameters	Lattice B25 (with superbends)
Circumference [m]	288
Beam pipe diameter [mm]	18
Momentum compaction α	$9.08 \; 10^{-5}$
Radiated energy/turn [keV]	441.543
Natural energy spread	$1.01 \; 10^{-3}$
Damping time x/y/E [ms]	5.9 / 10.4 / 8.4



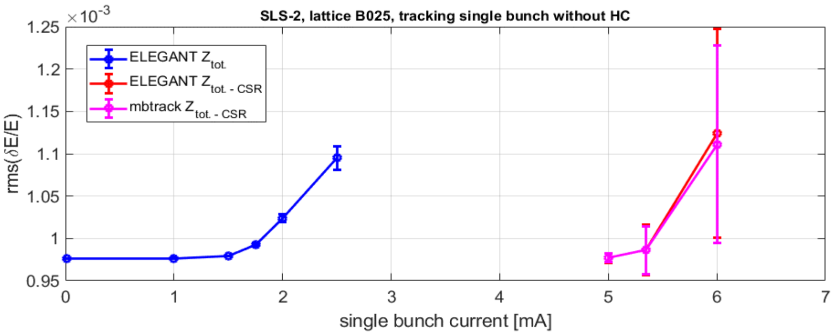


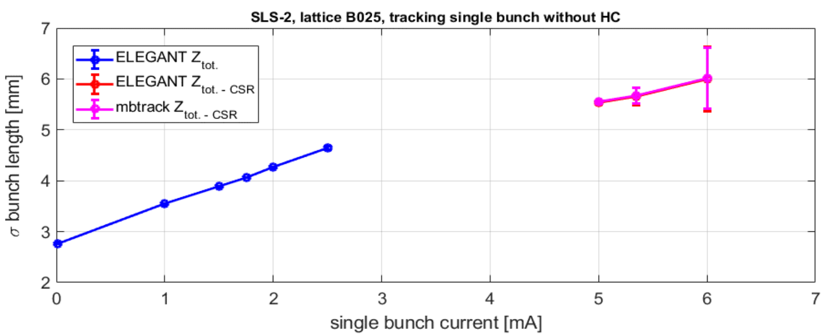




Courtesy: A. Citterio

Importance of CSR and Time Resolution



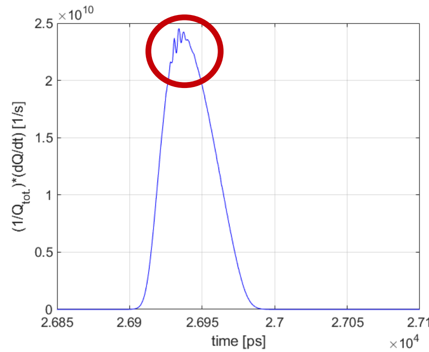


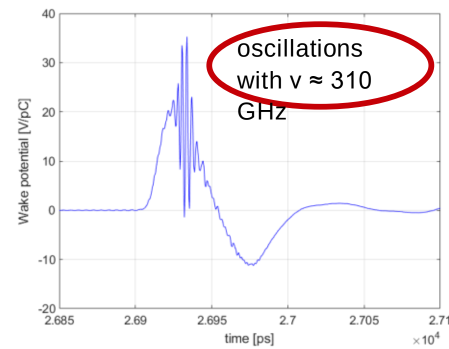
With CSR, $I_{sb,\,thr.}$ = 1.5 mA (ELEGANT tracking)

Without CSR, $I_{sb,\,thr.}$ = 5 mA (ELEGANT and Mbtrack tracking)

(single bunch, without harmonic cavity)

Bunch profile and wake potential for I_{sb} = 2.5 mA, SLS-2.0 lattice B25 without super super bend, Z_{tot}





In order to solve instable oscillations due to CSR at very high frequencies, ELEGANT simulations require very severe initial setting:

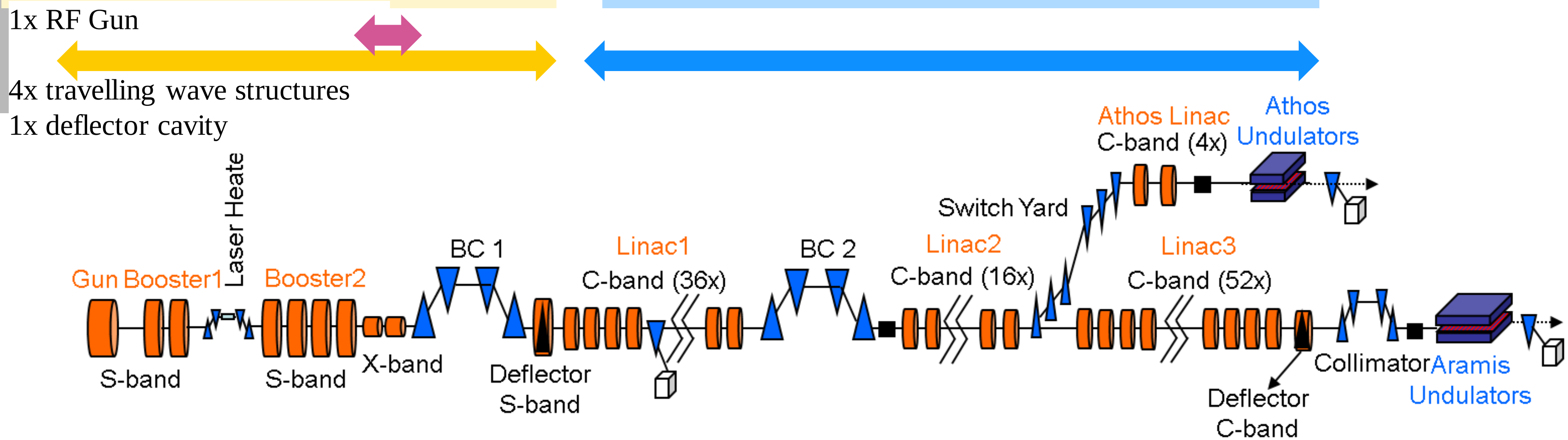
- 32E6 Macroparticles,
- CSR and RW impedance up to 600 GHz,
- Total frequency spectrum up to 1.2 THz for fine time resolution
- $2\times(2^{16}+1)$ bins in time domain ($\equiv \Delta t$ = 0.41 ps)

Because CSR wake is «anti-causal», Mbtrack tracking code cannot be used to take into account such a contribution.

Courtesy: A. Citterio

SwissFEL RF System Overview

6x S-band (2998.8 MHz)	1x X-band (11.9952 GHz)	26x C-band (5712 MHz) (phase 1 without Athos beam line)	RF stations



Highlight of RF system features:

- Technology: Normal conducting
- RF repetition rate: up to 100 Hz
- RF pulse width: 0.1 ~ 3.0 µs
- Num. of bunch/pulse: 1 ~ 2

Aramis beam stability requirements (RMS):

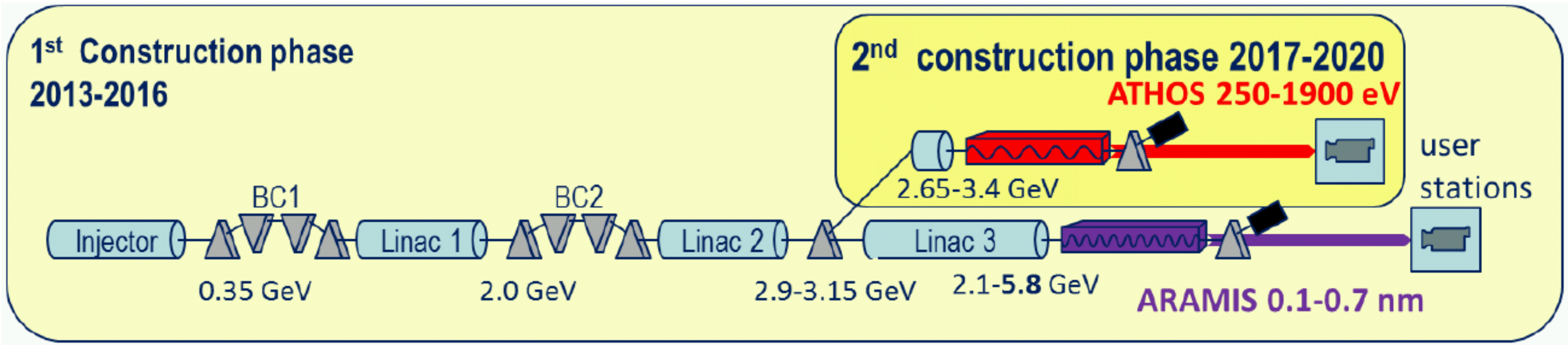
- Peak current (bunch length): < 5 %
- Beam arrival time: < 20 fs
- Beam energy: < 5e-4

RF stability requirements (RMS):

- S-band amplitude: < 1.8e-4
- C-band amplitude: < 1.8e-4
- X-band amplitude: < 1.8e-4
- S-band phase: < 0.018 degS
- C-band phase: < 0.036 degC
- X-band phase: < 0.072 degX

SwissFEL Project Summary & Outlook

Status (as of Sept. 2019)



All 34 RF systems are installed and in operation

Station		MV	deg
SINEG01	RF on beam	7.1	90.0
SINSB01	RF on beam	70.5	90.0
SINSB02	RF on beam	62.4	90.0
SINSB03	RF on beam	98.0	70.3
SINSB04	RF on beam	98.0	70.2
SINXB01	RF on beam	20.5	270.2
SINDI01	RF on delay	4.9	181.5
S10CB01	RF on beam	229.9	68.4
S10CB02	RF on beam	225.1	92.9
S10CB03	RF on beam	250.4	43.8
S10CB04	RF on beam	230.0	93.0
S10CB05	RF on beam	245.1	43.8
S10CB06	RF on beam	250.1	92.9
S10CB07	RF on beam	209.7	43.7
S10CB08	RF on beam	240.1	92.9
S10CB09	RF on beam	243.0	43.9

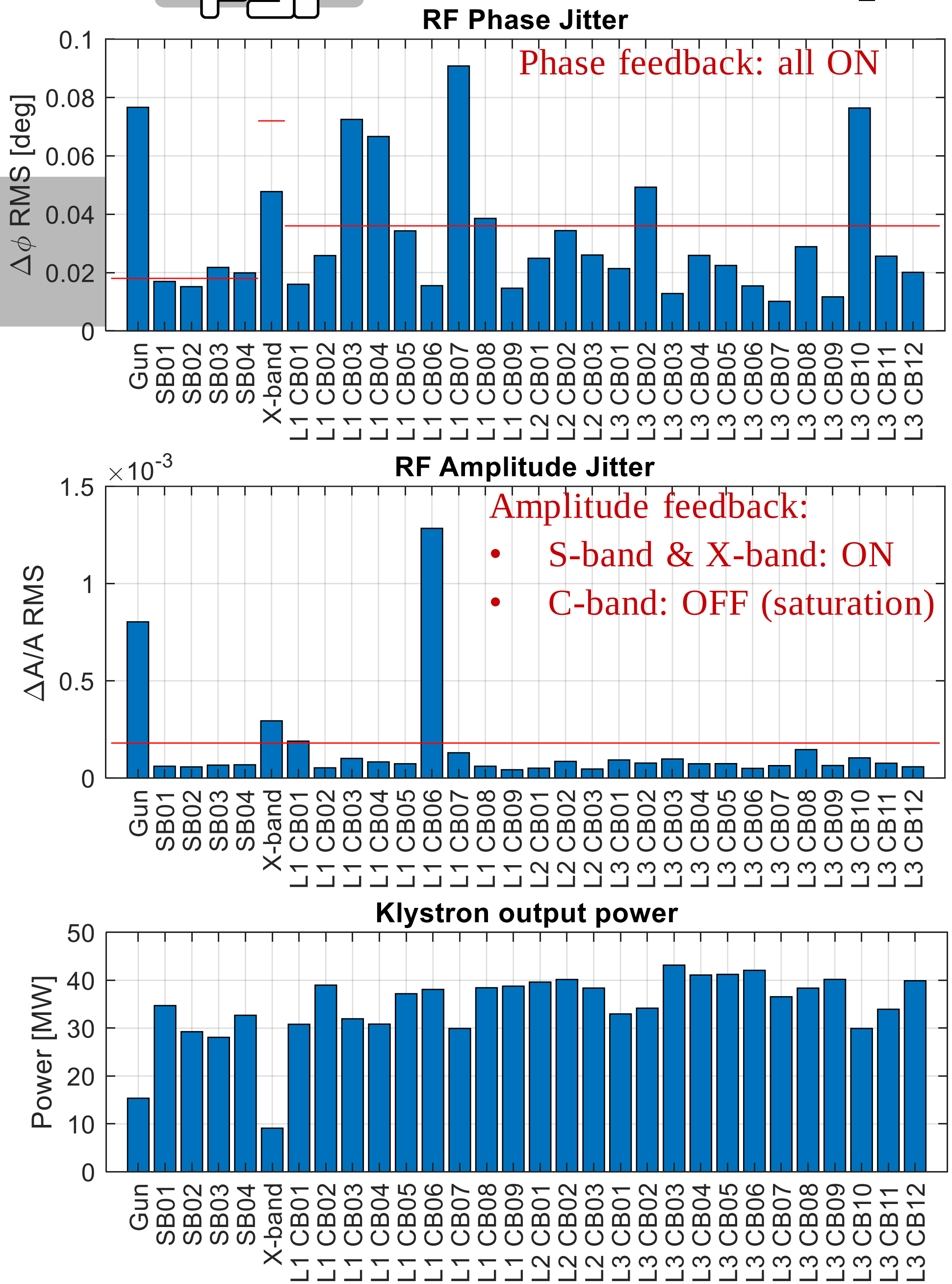
Station		MV	deg
S20CB01	RF on beam	245.0	90.0
S20CB02	RF on beam	250.0	90.0
S20CB03	RF on beam	240.0	90.0
S20CB04	RF on beam	245.0	90.0
S30CB01	RF on beam	230.3	80.3
S30CB02	RF on beam	247.9	99.7
S30CB03	RF on beam	246.8	80.3
S30CB04	RF on beam	242.9	99.7
S30CB05	RF on beam	247.1	80.3
S30CB06	RF on beam	245.0	99.7
S30CB07	RF on beam	240.2	80.3
S30CB08	RF on beam	241.8	99.7
S30CB09	RF on beam	242.9	80.3
S30CB10	RF on beam	240.5	99.7
S30CB11	RF on beam	248.8	80.3
S30CB12	RF on beam	240.3	99.7
S30CB13	RF on beam	245.3	90.1

0.370

Schedule

	2019	2020	2021
Aramis	**Consolidation and User operation**	**Consolidation and User operation**	**User operation**
Athos			
- dual bunch operation	**Establish permanent dual bunch**		
- RF systems installation & commissioning	**mod. development**	**Commissioning and user operation**	
- user operation			**User operation**

Station Pulse-to-pulse Amplitude and Phase Jitter



RF Station	Phase Tolerance (rms)	Voltage Tolerance (rms)
S-band (2.9988 GHz)	0.018 degS	0.018 %
C-band (5.7120 GHz)	0.036 degC	0.018 %
X-band (11.9952 GHz)	0.072 degX	0.018 %

- RMS jitter is calculated with the 10-min amplitude/phase data with beam in presence (RF rate 100 Hz, statistics with beam rate 25 Hz).
- Gun measurement problem:
  - Contains high-frequency noise (not averaged in pulse) and other passband mode (π/2-mode): **beam feels less jitter**.
  - Problematic cavity probes.
- Linac1 C-band #6 pre-amplifier failed and resulted in large amplitude drift in open loop operation.
- Large phase jitter in several C-band stations – Klystron or BOC multipacting.

Data collected from SwissFEL at July 13, 2019 13:44–13:54

Z. Geng et al. FEL 2019

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Wir schaffen Wissen – heute für morgen

Thank you for your attention!

+ Thanks to P. Craievich and Z. Geng for the SwissFEL slides!