PAUL SCHERRER INSTITUT

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Paul Scherrer Institut

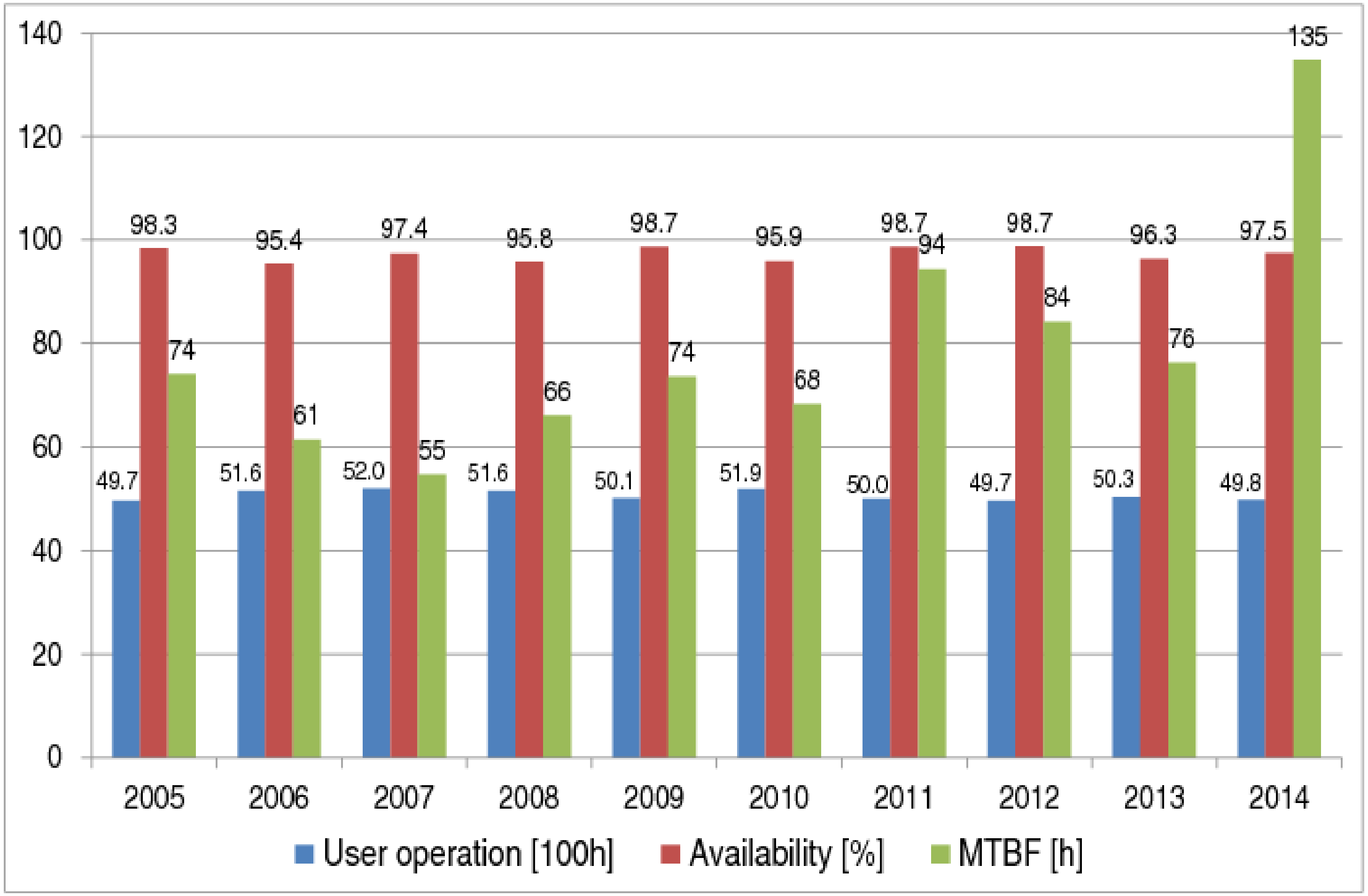
Haisheng XU for the PSI rf-group

RF operation at the SLS and upgrade to SLS-2

Overview

- Operation statistics
- LINAC and storage-ring RF failures and maintenance
- SLS-2 upgrade

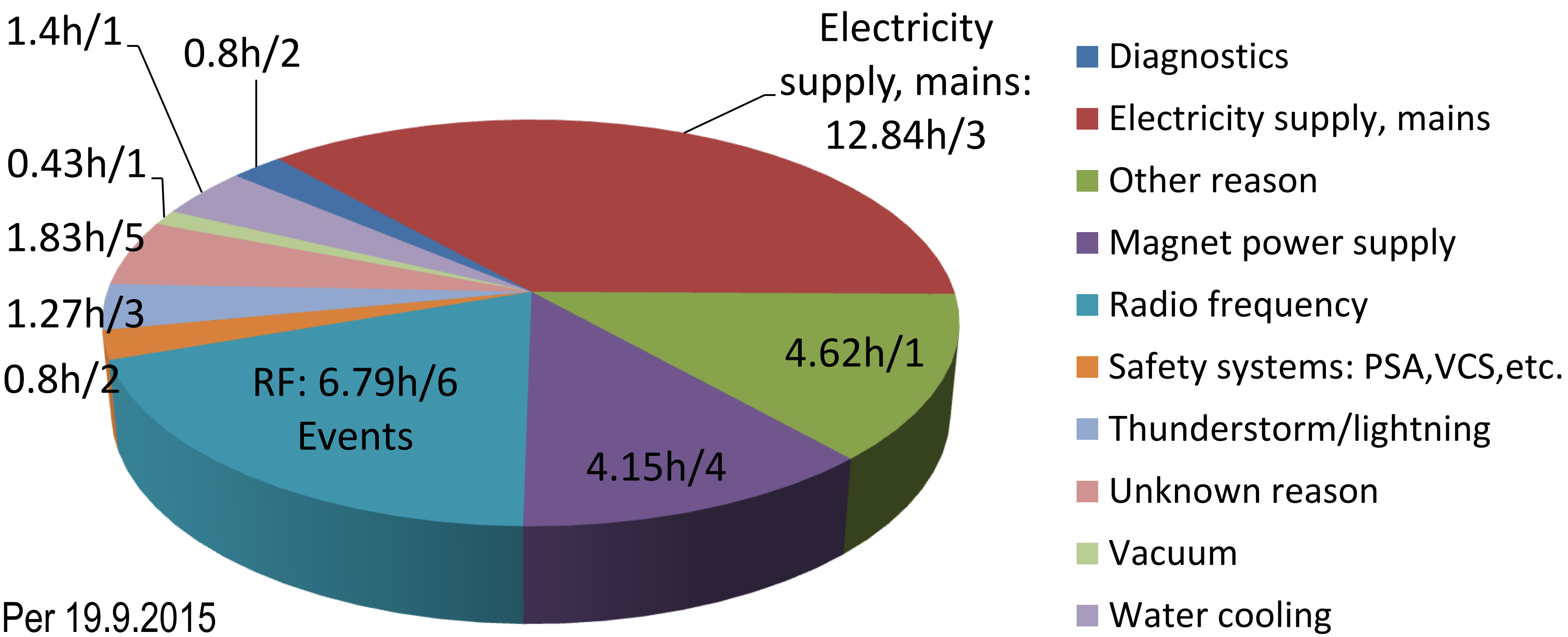
Operation Statistics



- **November 2014: Failure of Booster klystron (arcing at modulation anode cable)**
- **In 2014 less failures during user operation.**
  (Improved magnet power supplies and machine interlock system)

Operation Statistics 2015

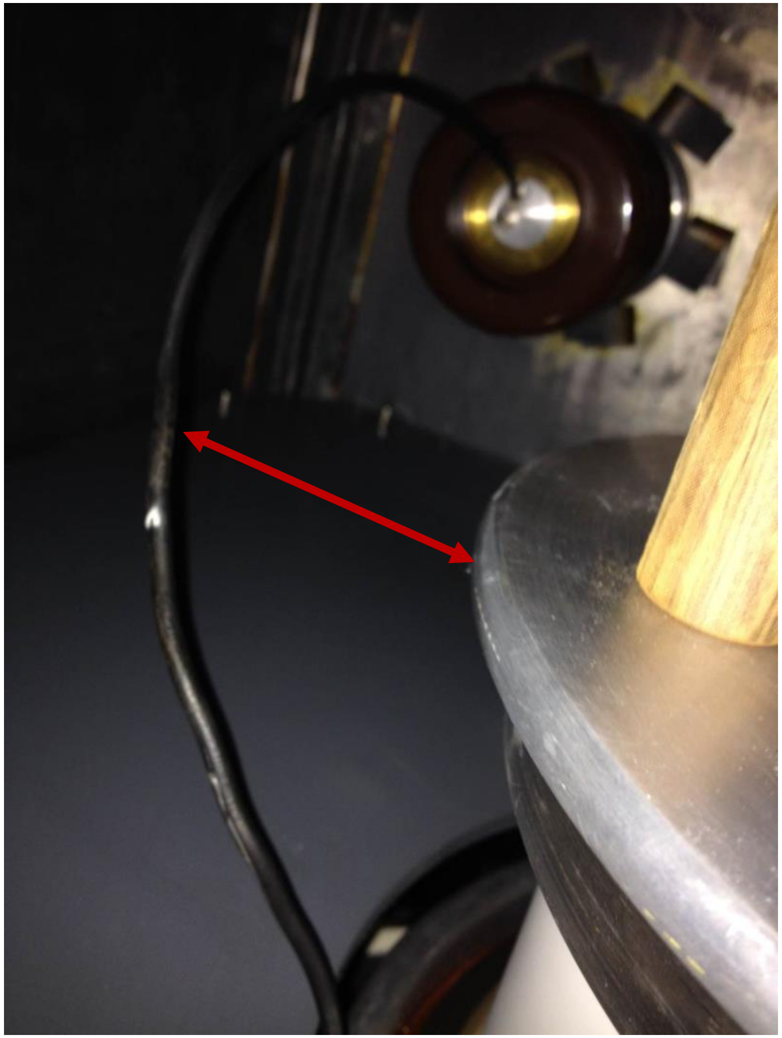
Faillure cause, total down-time and number of events:



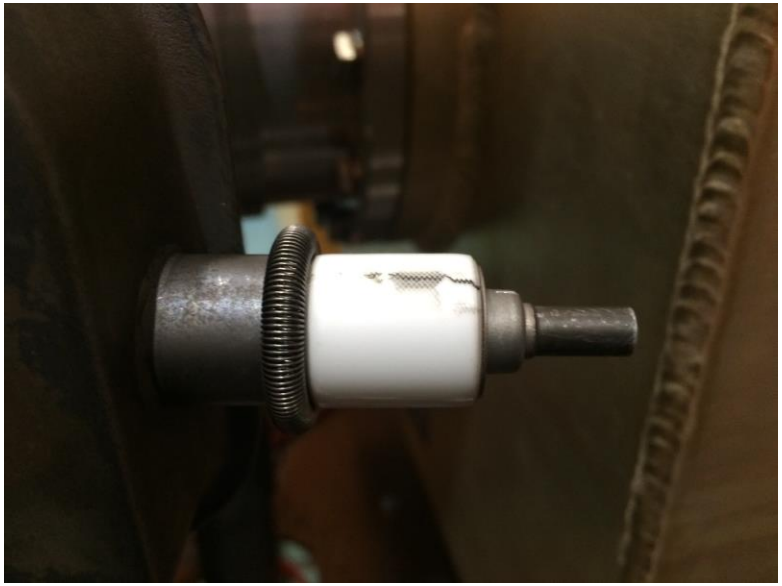
Per 19.9.2015

- **Failures at LINAC: power supplies, klystron body flowmeter**
- **Failures at storage-ring: klystron vacuum-pumps, false interlocks.**
- **Problems with S3HC: power failure, 2 x contamination at heat-exchanger**
- **Problem with circulator temperature compensation system (21.9.)**

500MHz Klystron Problems



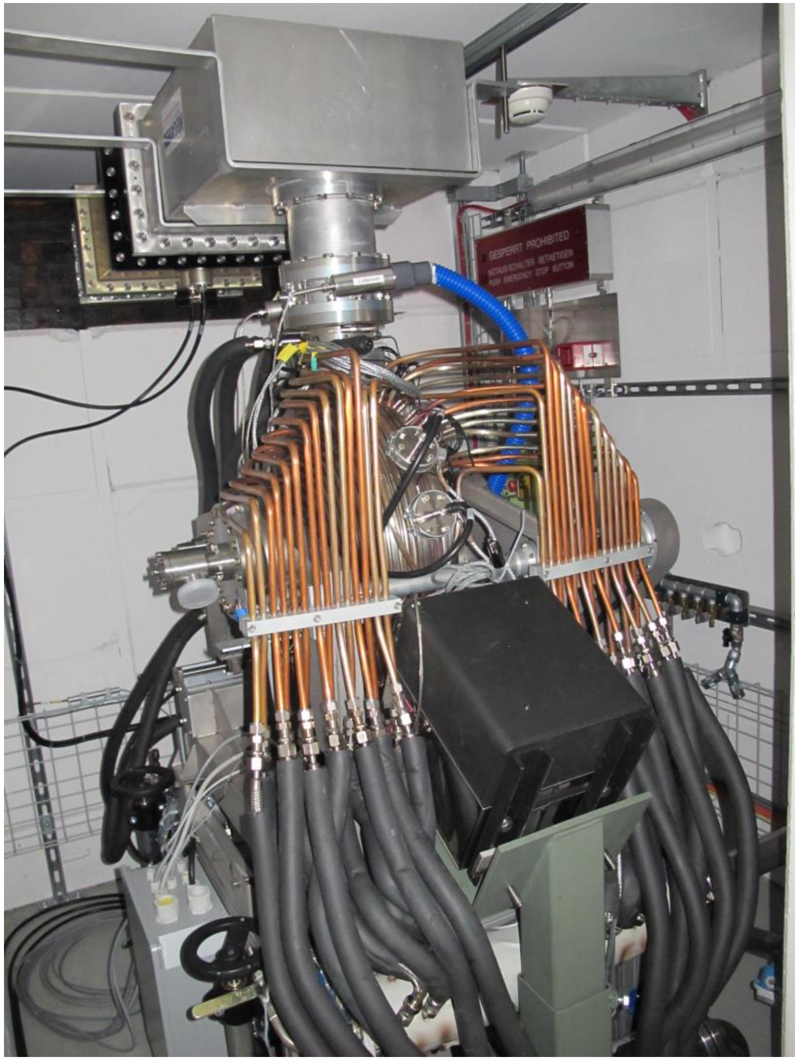
HV-deck of EEV Klystron
(cable was too close to the ring)



Connector of Klystron vacuum pump

- ✓ Arcing of modulation anode cable caused 5 hours downtime of booster RF-plant
- ✓ Vacuum problems, marks on IP-ceramic after high-potting
- ➢ Efficiency of refurbished klystron below specification
- ✓ Vacuum problems solved by high-potting on refurbished klystron

Storage-Ring: 3rd ELETTRA Cavity Replaced



✓Second ELETTRA cavity replaced in January 2015 shutdown

✓Third ELETTRA cavity replaced in August 2015 shutdown

❖Tuning motor was broken after bake-out

❑Fourth cavity installed in the testand for conditioning and testing

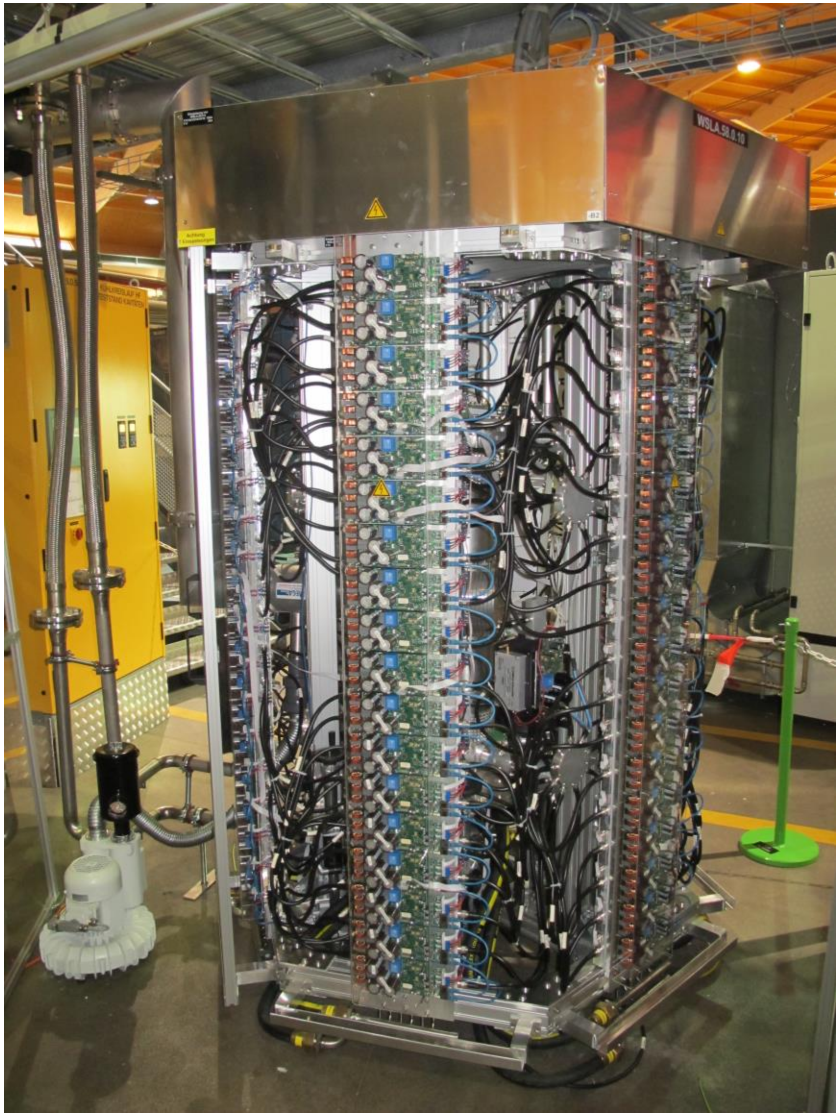
❑Installation of last new ELETTRA cavity in January 2016

✓All cavities run now with reduced flow rates in the wall-cooling and flange-cooling circuits

✓Tuning range reduced to half to avoid inelastic deformation

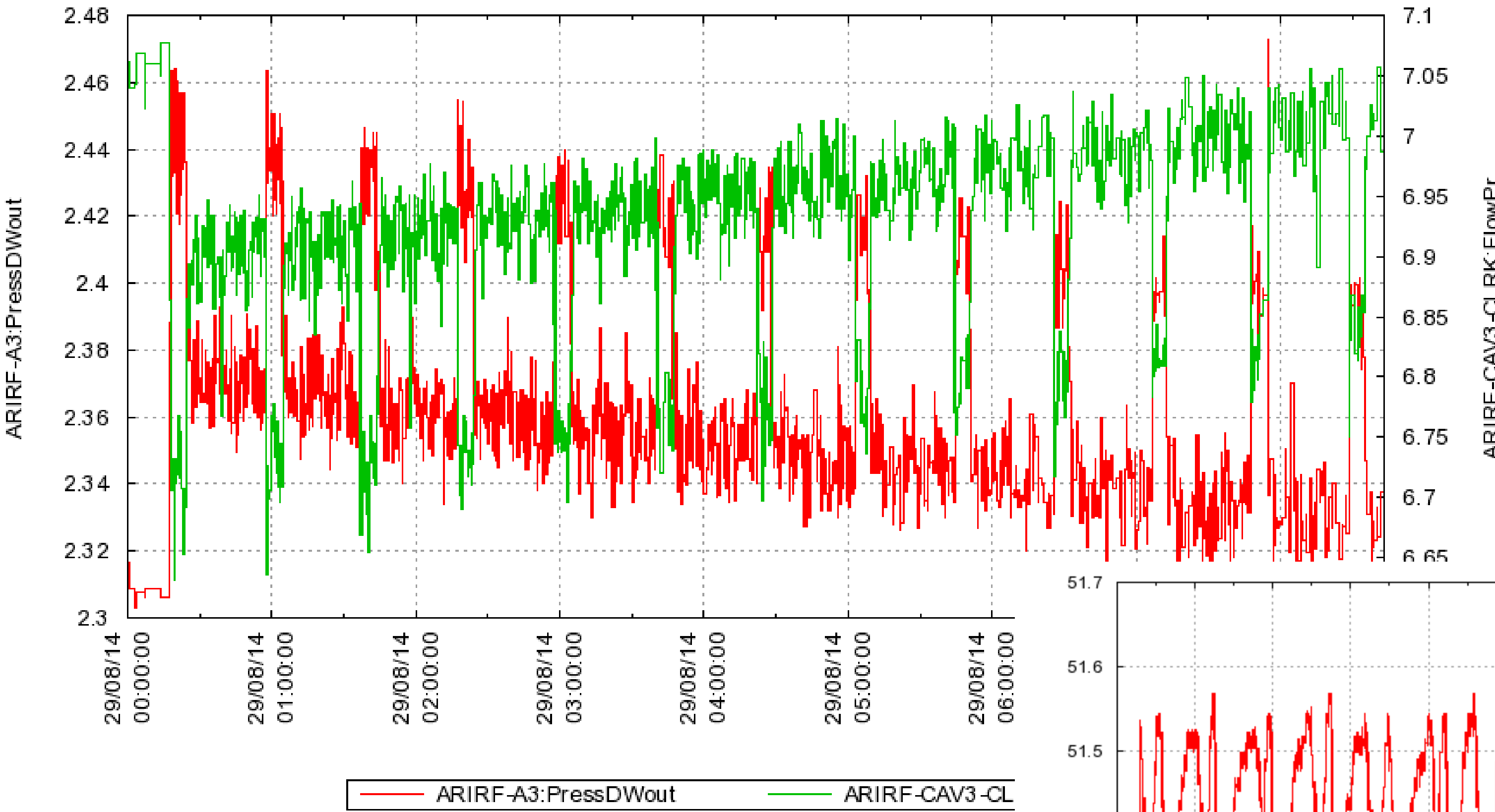
500MHz, 60kW Solid State Amplifier

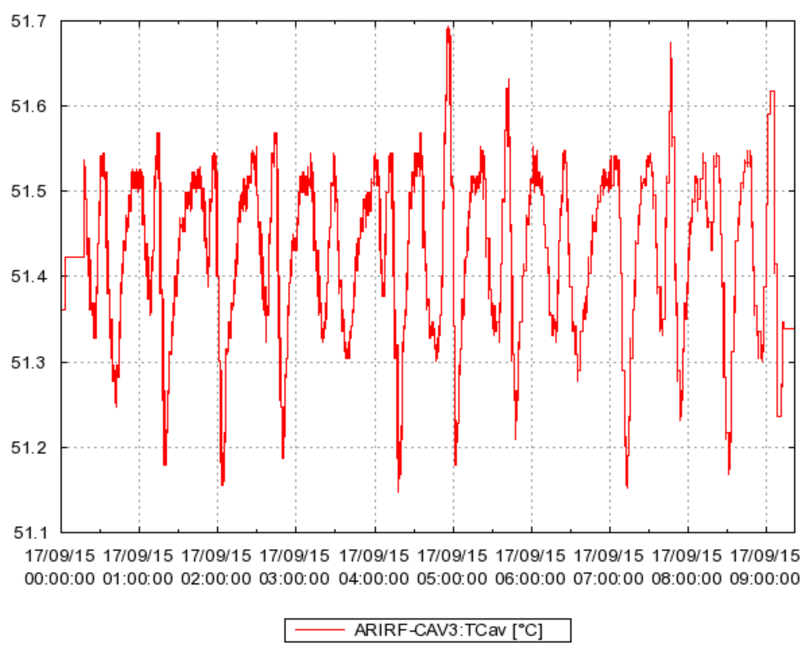
Solid state amplifier at the teststand:



- ✓ Installation of solid state amplifier at the teststand
- ✓ Setup of cooling system
- ✓ Test of cavity combiner with Ampegon and University of applied science Brugg-Windisch
- ❑ Interface to EPICS control system in progress (basic control possible)
- ❑ Tests with full power on cavity pending

Storage Ring Temperature /Pressure Fluctuations





Fast fluctuations of water pressure in the SLS main circuit lead to a flow rate change in the heat exchanger of the cooling rack

→Temperature oscillations at the cavity!

Other SLS RF Works & Outlook

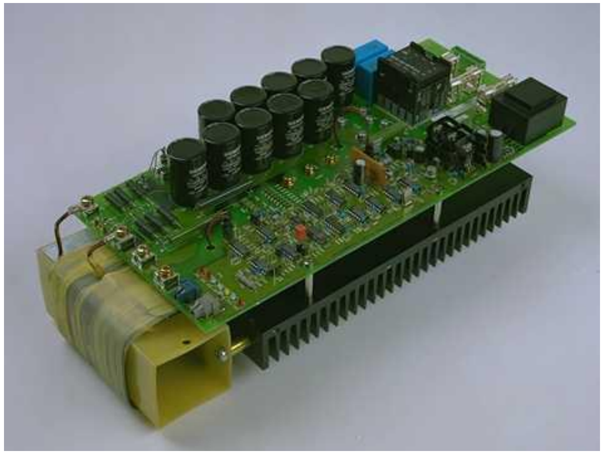
Accomplished:

✓LINAC spare solenoids finished (preparing for field-mapping and alignment)

✓Improved PLC of S3HC to allow reboot of temperature-measurement crate

✓Prototype fire detector of 500MHz Klystron power supplies installed and tested

✓Capacitors replaced at PSM HV modules of first 500MHz RF-plant (Klystron HV power supply)



Work in progress:

❑Improve PLC and Interface of S3HC

❑Replace the last storage-ring cavity in January 2016

❑Fire detectors for storage-ring klystron power supplies

❑Refurbish Klystrons at CPI and optimize efficiency

❑Replace capacitors of storage ring klystron power supplies (PSM HV-Modules)

❑Replace capacitors of LINAC klystron focus power supplies and LINAC solenoid power supplies

SLS-2 upgrade

- Constraints
  - Remain the locations and pointing directions of beamlines the same;
  - Keep circumference of the storage ring unchanged;
  - Re-use the injectors of the storage ring: electron gun, linac and booster;

- Ideas to achieve lower emittances ($\varepsilon_x \sim 100$ pm)
  - Anti-bends (AB)
  - Longitudinal gradient bends (LGB)
  - TBA → MBA (7BA)

- Challenges
  - Small circumference --- 288 m
  - Nonlinear optics optimization
  - Injection
  - **Collective instabilities** →
  - Magnets (LGB)
  - …

- RF frequencies
- Harmonic cavities
  - Bunch lengthening
  - Landau damping
- Passive or active harmonic cavities
- HOM damping

SLS and SLS-2 lattice parameters

Name	SLS*)	db02l	fa01f
status	*operating*	*baseline*	*fallback*
Emittance at 2.4 GeV [pm]	**5022**	**137**	**262**
Lattice type	TBA	**7**BA	**5**BA
Total absolute bending angle	360°	585°	488°
Working point $Q_{x/y}$	20.42 / 8.74	38.38 / 11.28	28.29 / 10.17
Natural chromaticities $C_{x/y}$	–67.0 / –19.8	–67.5 / –36.0	–64.1 / –39.9
Optics strain 1)	7.9	**5.6**	8.9
Momentum compaction factor $[10^{-4}]$	6.56	–1.39	–1.86
Dynamic acceptance [mm.mrad] 2)	**46**	**10**	**17**
Radiated Power [kW] 3)	205	228	271
rms energy spread $[10^{-3}]$	0.86	1.05	1.15
damping times x/y/E [ms]	9.0 / 9.0 / 4.5	4.5 / 8.0 / 6.4	5.0 / 6.8 / 4.1

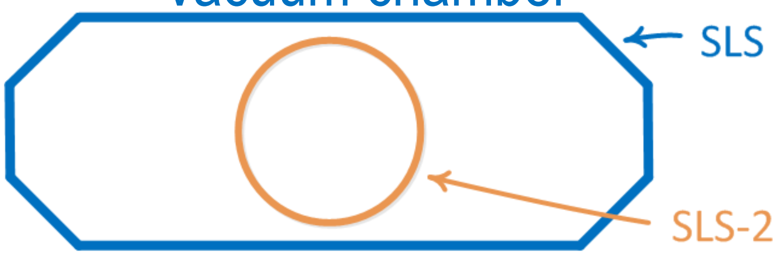
1) product of horiz. and vert. normalized chromaticities C/Q
2) max. horizontal betatron amplitude at stability limit for ideal lattice
3) assuming 400 mA stored current, bare lattice without IDs
*) SLS lattice `d2r55`, before FEMTO installation (<2005)

Courtesy of A. Streun

Collective instabilities in SLS-2

- Impedance
  - **Resistive-wall impedance --- small-aperture vacuum chamber, NEG coating**
  - Geometric impedance --- RF cavities, BPMs, kickers, IDs, etc.
  - CSR impedance --- longitudinal gradient bends (strong B-field)

Vacuum chamber



- Round chamber
- Vertical inner gap ~ 20 mm
- 1 μm NEG coating
- Use copper chamber to reduce the resistance

- Momentum compaction factor α_c
  - Small (1st-order) α_c --- high-order α_c --- RF bucket Distortion
  - Negative α_c
- Transverse collective instabilities
  - Head-tail instability
  - …
- Longitudinal collective instabilities
  - **Microwave instability**
  - Multi-bunch instability
  - …

→ RF parameters

Microwave instability

- Average current → **400 mA**
  - @ 100 MHz RF, uniform filling pattern, I_b = 4.17 mA (2.5×10^{10} e/bunch)
  - @ 500 MHz RF, uniform filling pattern, I_b = 0.834 mA (5.0×10^{9} e/bunch)

- RF voltage and phase
  - Momentum acceptance: 5% (**0.811 MV** @ 100 MHz or **1.43 MV** @ 500 MHz)
  - Flattened potential well

- PyHEADTAIL* simulation
  - 1 million macroparticles, 500 slices/bunch
  - Synchrotron radiation effects have not yet been built in the code. We implemented the SR effects by the following manner**:

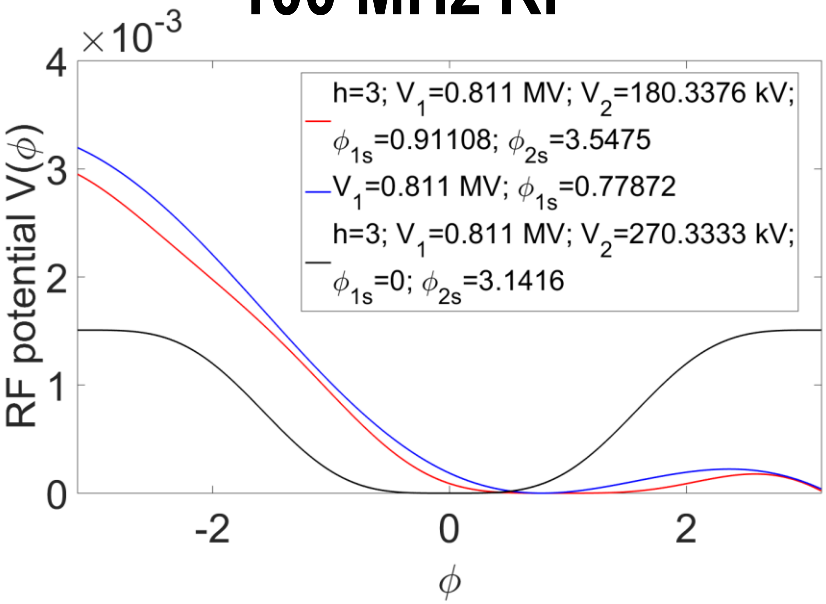
$$\delta\Big|_{n+1} = \frac{\Delta p}{p_0}\Big|_{n+1} = \underbrace{\delta\Big|_n \cdot e^{-\frac{2T_0}{\tau_E}}}_{\text{Radiation damping}} \underbrace{- \frac{U_0}{\beta^2 E_0}}_{\text{Average energy loss per turn}} + \underbrace{rand \cdot \sigma_\delta \cdot \sqrt{3 \cdot \left(1 - e^{-\frac{4T_0}{\tau_E}}\right)}}_{\text{Quantum excitation}}$$

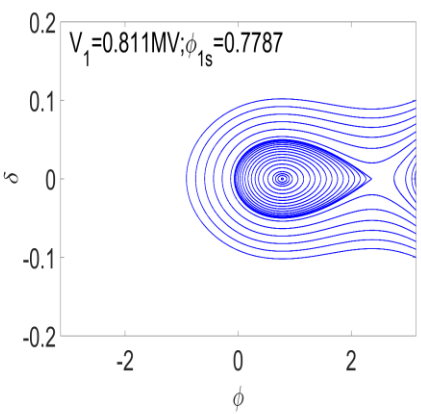
Radiation damping — Average energy loss per turn — Quantum excitation

[*] CERN PyHEADTAIL simulation code for simulation of multi-particle beam dynamics and collective effects
[**] Andreas Streun, PhD Thesis, 1992

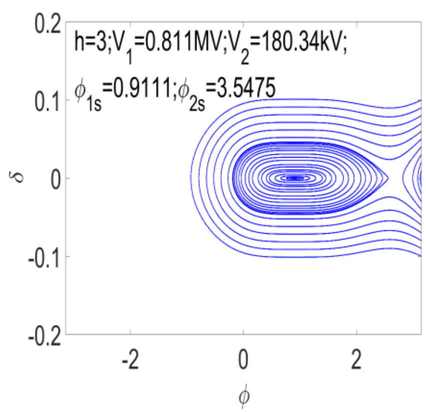
RF voltages and phases @ different frequencies

100 MHz RF



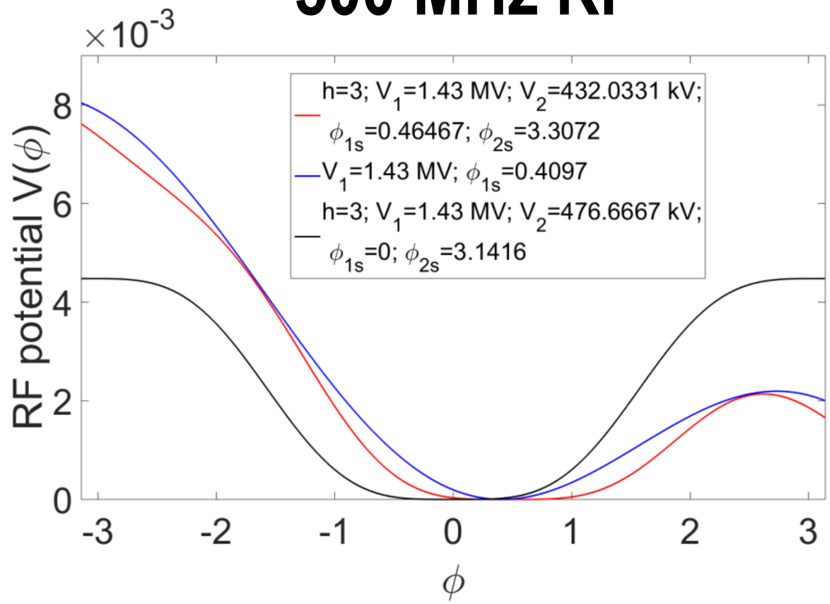


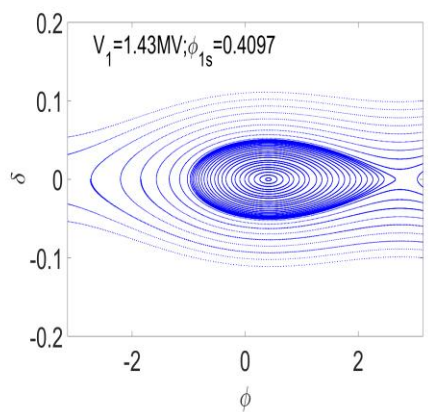
w/o harmonic cavity



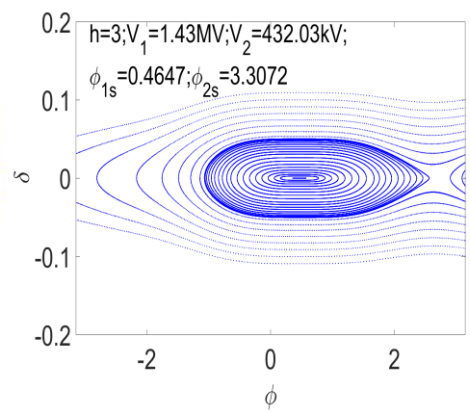
with harmonic cavity

500 MHz RF





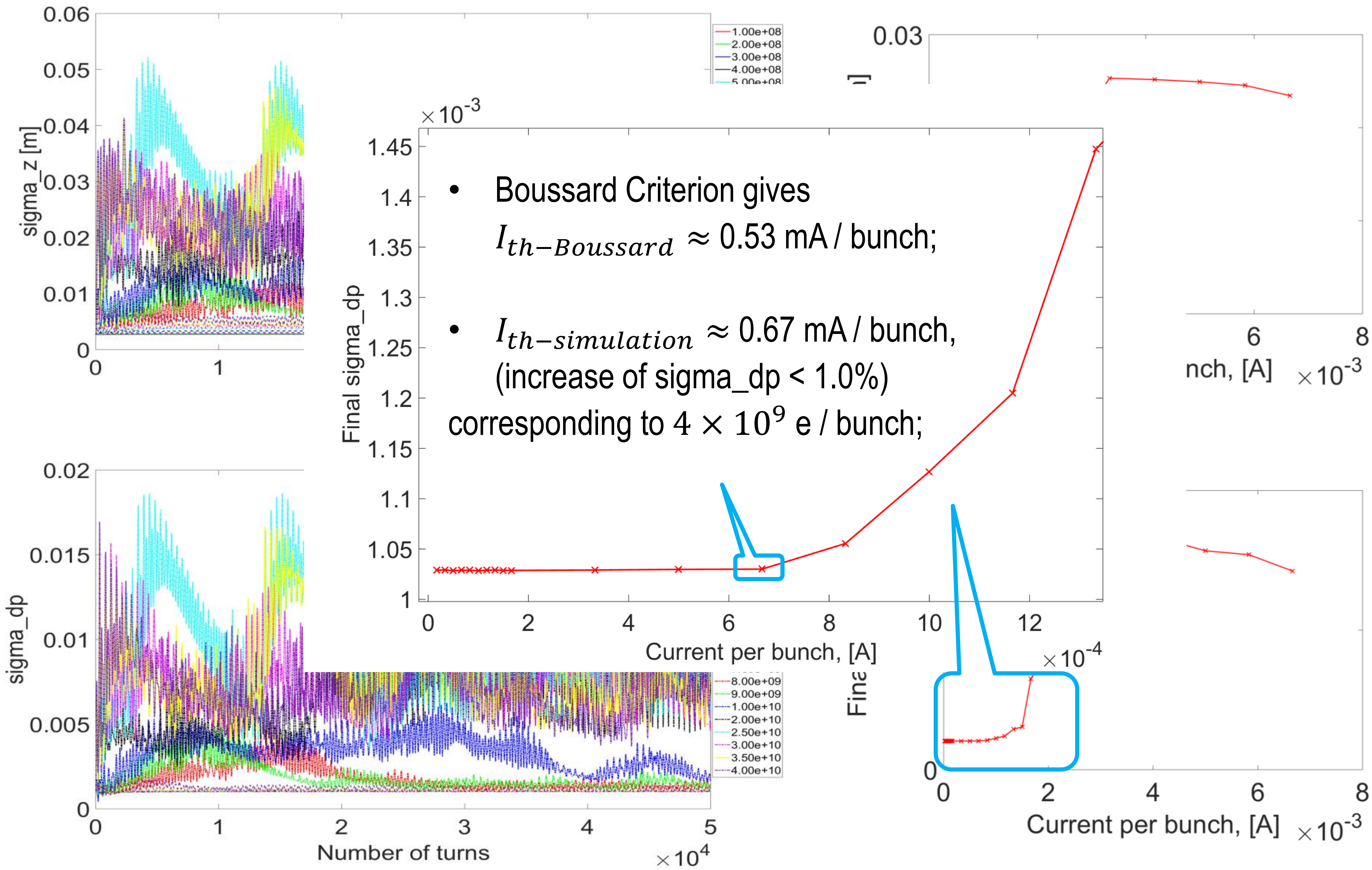
w/o harmonic cavity



with harmonic cavity

PyHEADTAIL Simulation, 500 MHz RF

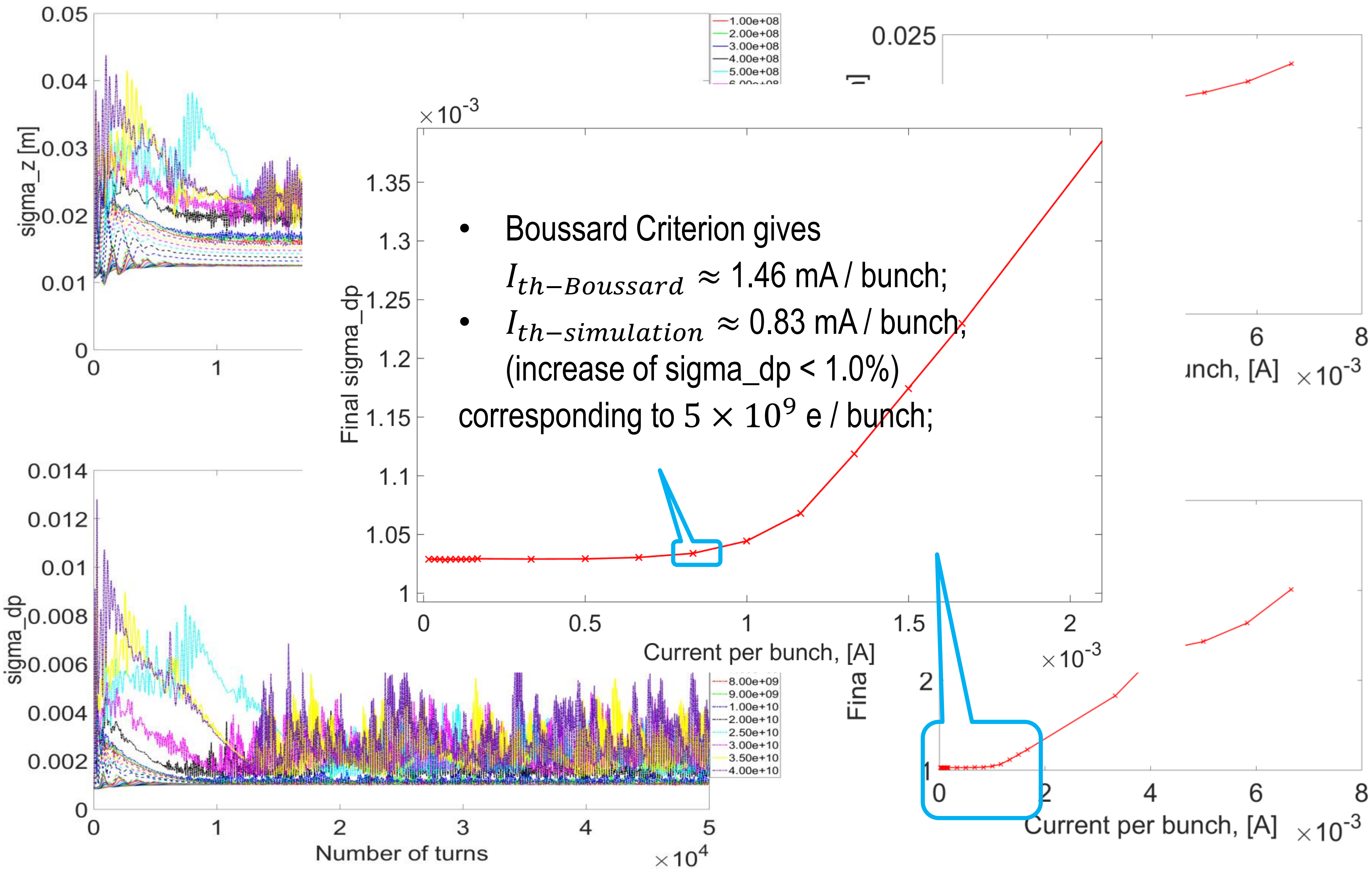
No harmonic cavities, V_1=1.43 MV, $d\phi_1$=2.7319



- Boussard Criterion gives $I_{th-Boussard} \approx$ 0.53 mA / bunch;
- $I_{th-simulation} \approx$ 0.67 mA / bunch, (increase of sigma_dp < 1.0%) corresponding to 4×10^9 e / bunch;

PyHEADTAIL Simulation, 500 MHz RF

With 3rd harmonic cavities, V_1=1.43 MV, V_2=432.03 kV, $d\phi_1$=2.6769, $d\phi_2$=-0.1656



- Boussard Criterion gives $I_{th-Boussard} \approx$ 1.46 mA / bunch;
- $I_{th-simulation} \approx$ 0.83 mA / bunch, (increase of sigma_dp < 1.0%)

corresponding to 5×10^9 e / bunch;

Threshold of microwave instability in different cases

Parameters	100 MHz primary RF		500 MHz primary RF	
	No harmonic cavity	With 3rd harmonic cavity	No harmonic cavity	With 3rd harmonic cavity
Impedance included	Resistive-Wall impedance only; round chamber with inner radius 10 mm; 1μm NEG coating and copper chamber;			
Threshold by Simulation (mA/bunch)	0.33	10	0.67	0.83

Summary & Outlook for SLS-2 work

- We are approaching a baseline design of SLS-2 storage ring.
- Harmonic cavities are necessary for SLS-2 based on the preliminary study of microwave instability.

- Choose proper RF parameters for SLS-2 based on more systematic studies of collective instabilities.
- Carry out detailed design of RF system for SLS-2.

Acknowledgement

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- Thank people in SLS-2 team for their comments and discussion.

- Thank Kevin Li, Adrian Oeftiger, Michael Schenk for their supporting and discussion on the usage of PyHEADTAIL.

Thank you very much for your attention!