PAUL SCHERRER INSTITUT

PSI

Roger Kalt on behalf of the LLRF team :: Paul Scherrer Institut

Lab Talk: LLRF Status and Activities at PSI

LLRF Workshop 2019, Chicago

30.09.2019 - Presented at LLRF Workshop 2019 (LLRF2019, arXiv:1909.06754)

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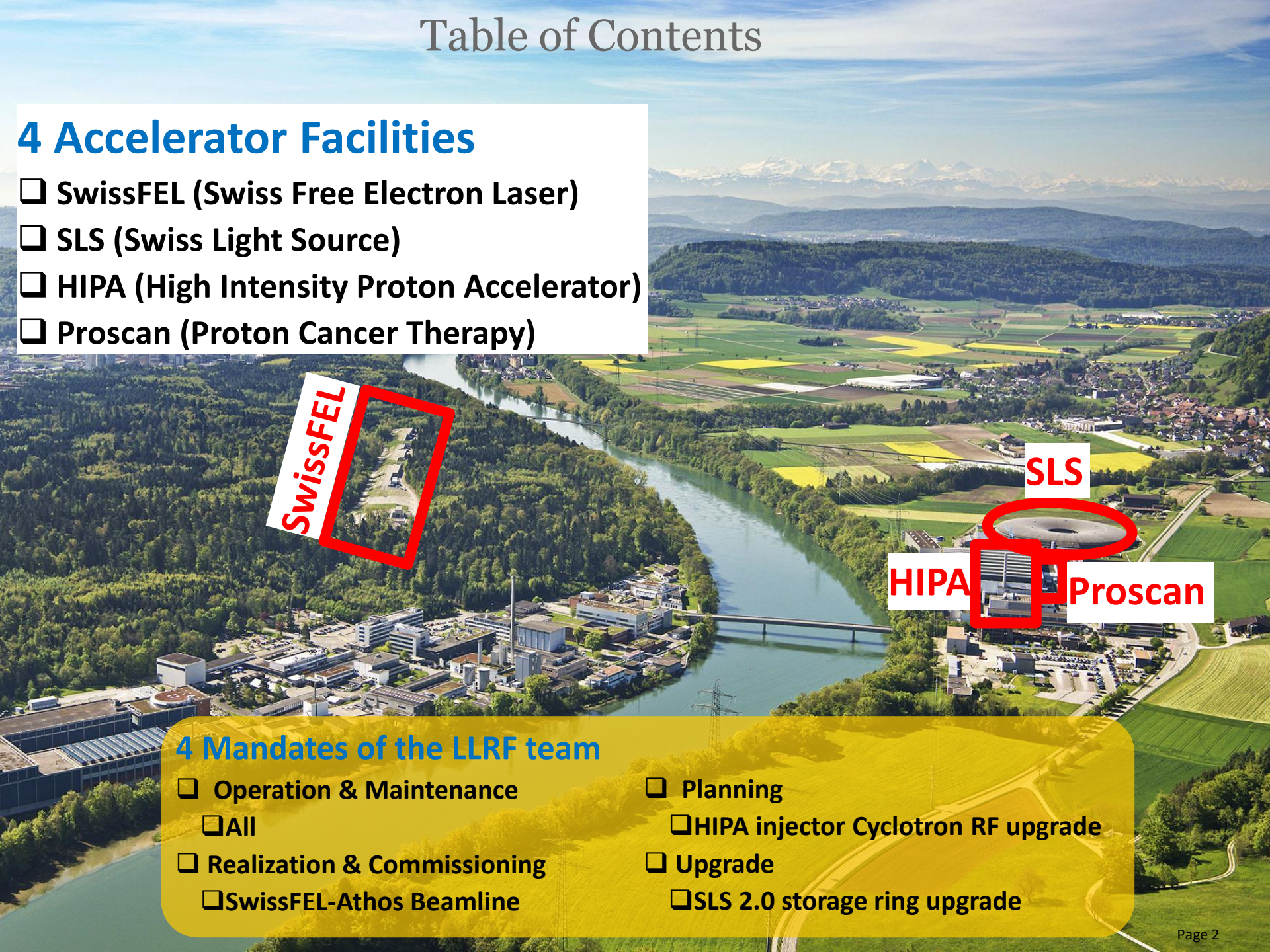
4 Accelerator Facilities

- ❑ SwissFEL (Swiss Free Electron Laser)
- ❑ SLS (Swiss Light Source)
- ❑ HIPA (High Intensity Proton Accelerator)
- ❑ Proscan (Proton Cancer Therapy)



4 Mandates of the LLRF team

- ❑ Operation & Maintenance
  - ❑ All
- ❑ Realization & Commissioning
  - ❑ SwissFEL-Athos Beamline
- ❑ Planning
  - ❑ HIPA injector Cyclotron RF upgrade
- ❑ Upgrade
  - ❑ SLS 2.0 storage ring upgrade

RF systems in operation

Facility:	HIPA	SLS	Proscan	SwissFEL
LLRF operated since	1980's	2000	2005 (1980's)	2015
System Type	Analog	Analog	Analog	Digital
RF Op. Type	CW	Pulsed 3 Hz + CW	CW	Pulsed 100 Hz
Hardware	Own design	External institute	Internal HIPA + Ext.company	COTS (Controls HW) + own RF
Controls integration	Analog interface	Analog interface	Analog interface	Full remote access

Table: LLRF systems in operation:

SwissFEL: 6 x 3 GHz ; 2 x 12 GHz; 28 x 5.7 GHz (*2 types*) ⇒ 36 RF Stations

(today with test facility and Athos)

HIPA: 8 x 50 MHz (*3 types*); 4 x 150 MHz (*3 types*); 1 x 500 MHz ⇒ 13 RF Stations

(today situation with test facility)

SLS: 7 x 500 MHz (*3 types*); 2x 3 GHz; 1x1.5 GHz SC passive ⇒ 10 RF Stations

(today with test facility)

Proscan: 1 x 72.8 MHz ⇒ 1 RF Station

total **60 RF Stations**

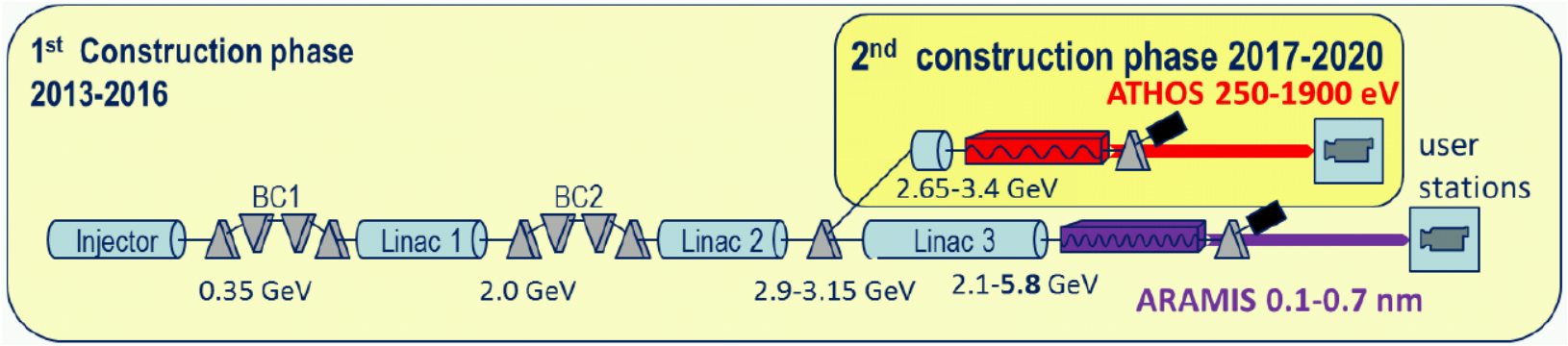
- ❑Main Beamline Aramis: Operation & Maintenance
- ❑2nd Beamline Athos: Realization & Commissioning
- ❑RF Teststand: Installation of C-band RF system

SwissFEL Project Summary & Outlook

Status (as of Sept. 2019)

1x X-band LLRF FE devel., modulator in-house devel.

1x C-band LLRF installed, modulator commissioning…



All 34 RF systems are installed and in operation

Schedule

	2019	2020	2021
Aramis	**User operation**	**replace X-band LLRF FE**	
Athos			
- dual bunch operation	**Establish permanent dual bunch**		
- RF systems installation & commissioning	**LLRF FE & mod. development**	**Commissioning**	
- user operation			**User operation**

FE : Analog front-end for LLRF (Receiver, Upconverter)

SwissFEL LLRF – Operation & Optimization

RF- and Beam-Stability Analysis

- ❑ LLRF system fulfills stability requirements
- ❑ Model-based prediction of RF vs. beam jitter
- ❑ Identify critical RF stations, then jitter contributing subsystems like:
  - ➢ HV modulator — Different issues, e.g. loose conn.
  - ➢ Pre-amplifier — Broken units – repair program
  - ➢ Klystron multipactor — Different for each klystron
  - ➢ BOC multipactor — A problem below 40 MW input power

LLRF Tuning for Dual Bunch Operation

- ❑ Keep basic low-level RF functionalities on lower-layer as is
- ❑ High-level setup and automation tools for **independent** tuning of both bunches created.

RF Systems Availability Analysis

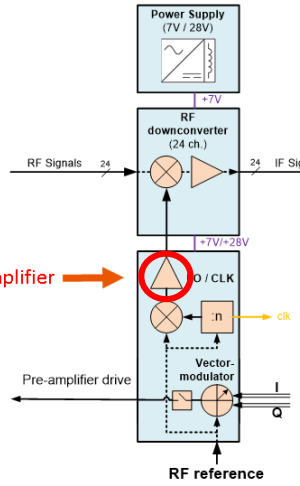
- ❑ Implemented dedicated RF systems fault events database

BOC: Barrel Open Cavity RF Pulse Compressor

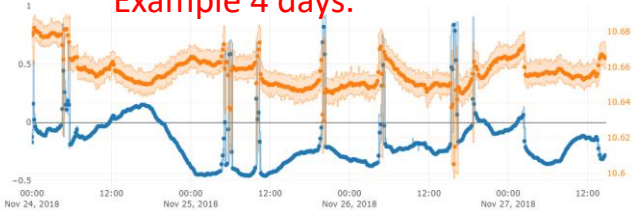
SwissFEL LLRF – Problems and Mitigations

Low-Level RF Hardware

- ❑Fuse broken, PS broken, cable loose
  - ➢ *Check & tighten all cables 1x / year*
- ❑Commercial LO amplifiers have production problems: Results in sudden phase jumps up to 1.5 deg.
  - ➢ *In-house development of low-noise narrow-band LO amplifier*



Jumps of the LO amp result in phase jumps in all Rx channels. Example 4 days.

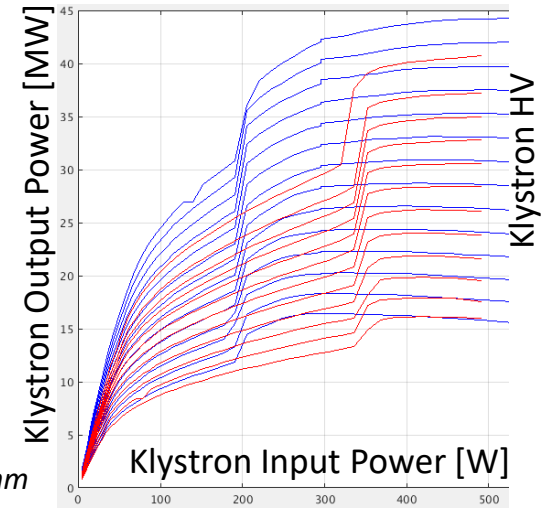


Blue: Reference phase meas.
Orange: LO Amp RF level

Low Level RF Software / Algorithms

- ❑Sudden software crash or stall, ~10-20 events / year
  - ➢ *Reboot, have a proper configuration parameters restore mechanism.*
- ❑Gun recovery from RF trip takes ~20min
  - ➢ *Instead of pickups implement virtual probe based on FOR/REF dir. coupler sig.*
- ❑Race conditions of LLRF trigger vs. RF phase reference
  - ➢ *FPGA based race detection and automatic correction*
- ❑BOC detuning over LLRF phase measurement stuck
  - ➢ *Control room alarms on the ACC voltage: Expected vs. measurement*
- ❑Klystron output RF amplitude setting procedure is not robust enough for all use cases
  - ➢ *Klystron LUT, forbidden multipactor areas, HV feedback, operation pt. det. algorithm*

Example C-band station



BOC: Barrel Open Cavity RF Pulse Compressor

- Operation & Maintenance of old RF stations
- Implementation & Commissioning for Injector Cyclotron RF upgrade

HIPA Injector Cyclotron RF Upgrade Project

Old analog LLRF

Dig. LLRF (installation partly completed)

RF Upgrade Project General Scope

- ❑Exchange of two 150 MHz resonators with 50 Mhz
- ❑Complete renewal of RF systems of allresonators

Status LLRF Upgrade

- ❑Low-power tests with cavity + tuner plungers done
- ❑Fw/Sw implementation on-going
  - ➢ Generic re-usable code open-sourced on GitHub.com/psi_fgpa_all
- ❑RF frontend HW prototypes [filters, selectable attenuators] produced & characterized (pizza box style)
- ❑HW installations & cabling partly completed

Poster
M. Stoll
R. Kalt

RF Upgrade Project Roadmap

- ❑Solve cavity tuner plungers and hot-spot problems at the 50 MHz RF test stand
- ❑Amplifier chain RF-commissioning stand-alone
- ❑Amplifier chain connection to the already installed cavity

LLRF Upgrade Roadmap

- ❑System integration & exception handling tests (e.g. startup)
- ❑Handle >90dB dynamic range for cavity tuning

- Operation & Maintenance
- Planning for SLS 2.0 Upgrade

SLS → SLS 2.0 upgrade preparatory phase

Goal: **Upgrade storage ring to provide factor >30 improved brightness + harder X-rays**

For all subsystems such as RF/LLRF: Upgrade to ensure other 20+ years operation, to optimize operation + maintenance cost, optimize perf. …

➔ Upgrade analog to digital 500 MHz LLRF / tuning system.

Schedule (simplified)

	2019	2020	2021	2022	2023	2024
SLS-2 preparatory phase						
financing period						
procurement/testing/pre-assembly						
maximum "dark" period						

Status

1. Decision for SSA's in Aug-2019, but some klystrons may stay
2. Internally with other groups next **processing platform options** evaluated: **CompactPCI-Serial** or **internal platform** developed for BPM's.
3. Upgrade of Linac RF stations (currently with feed-forward only) with the SwissFEL type digital LLRF (exact fit: pulsed 3 Hz @ S-band)

Summary

SwissFEL

- LLRF System weak points known – most of them are in software / algorithms.
  - Replacement of the commercial LO amplifiers with in-house development.
  - Consolidation of the RF amplitude setting procedure
- Studies like RF vs. beam jitter to be continued → Talk
  - Identified weak RF stations and subcomponents
  - LLRF is not the limiting subcomponent for the critical RF stations such as injector S- and X-band.
- Operation:
  - Establish dual bunch operation as default
  - Beam-rate: Go up to 100 Hz
  - Training of other colleagues for operation procedures and problem handling.

HIPA Injector Cyclotron Upgrade

- LLRF upgrade to new digital LLRF on-going, first RF station in operation 2020.

SLS 2.0 Upgrade

- Next processing platform selection process almost completed.
- Implementation of prototype 500 MHz prototype LLRF for RF test stand 2020

My thanks go to

- All team members
- All colleagues for their contributions to the workshop