Thomas Schietinger on behalf of SwissFEL expert groups :: Paul Scherrer Institut

Machine systems overview

4th SwissFEL Performance Workshop, 26 January 2022

Contents

- Timing & synchronization (incl. BAMs)
- Gun & seed laser systems
- Pump laser systems
- RF systems
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  - Low-level
  - Resonant kicker and septum
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- Undulators
- Controls
- SwissFEL global issues
- Summary & conclusion

Many thanks to all who provided information and slides!!!

(Cezary Sydlo)

Timing & Synchronization – overview

- **Major systems:**
  - Generation and distribution of low noise RF references (for 40 stations)
  - 28 RF doublers for 5.712 GHz
  - 8 laser-locks (+ HERO seed laser, – Jaguar gun laser this year)
  - 4 BAMs (2 more on hold) with two “experimental” stabilized links
  - 8 142.8-MHz stations plus sub-distribution
- More than 200 19”Crates and more than 280 (soft)-IOCs
- **Critical lack of personnel!**
  - 4 persons (incl. GL), 3 positions still to be filled, few suitable candidates apply

After various upgrades the system delivers world-class performance! 11 fs (rms)!

Beam arrival-time jitter in Aramis line measured to be around 7 fs (rms)!

(Cezary Sydlo)

Timing & Synchronization – status

- **Achieved** in 2021:
  - **BAM reference upgrade** for SARCL01-DBAM110 & SARUN20-DBAM020
  - Decreased **machine-vs-BAM jitter** ⇒ **bottleneck is the current analog laser-lock**
  - Upgrades to **reference generation and distribution** (in 2020/2021)
  - **System extensions:** Athos laser synchronization, new RF stations, optical power stabilization for synchronization of lasers (VVOA), …

- **Delayed** due to lack of personnel:
  - **Digital laser-lock** development delayed due to prioritization issues (SLS 2.0)
  - Upgrades with **custom optical links, optical cross-correlation and BAMs**

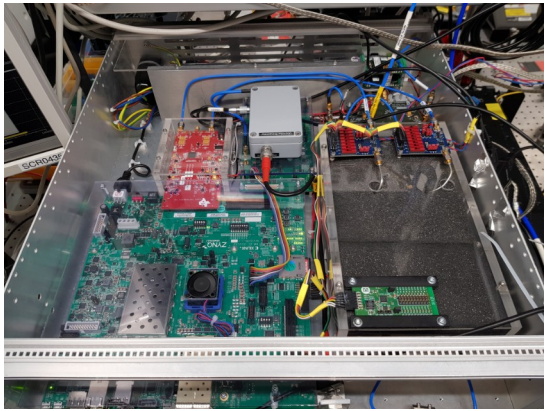
Many requests, changes, processes, workarounds and failures make it difficult to focus on core objectives. Many dependencies on other groups!

Complex, heterogeneous systems – many different clients rely on them!

Timing & Synchronization – plans & outlook

(Cezary Sydlo)

- **Digital laser-lock:**
  - Own collection of evaluation boards and experimental electronics works, but is **not complete yet**. Mainly waiting for parallel firmware developments.
  - Initial results show superior performance.
  - Final hardware development compromised by concurrent developments and prioritizations. Hope to have first prototypes available in summer/fall 2022.



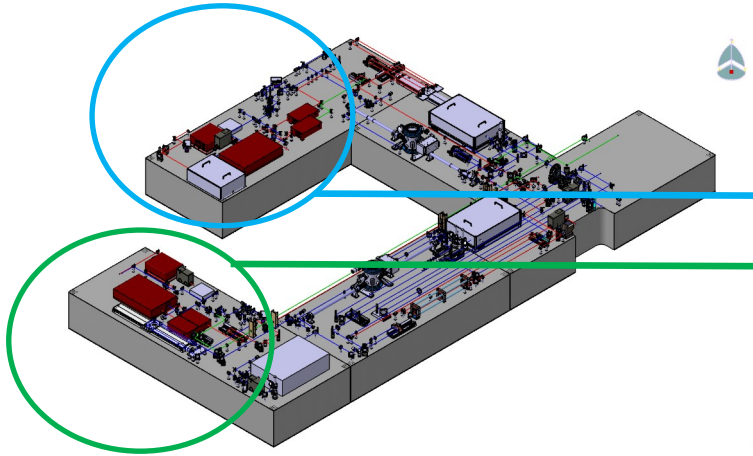
Laser lock test setup in WLHA/005

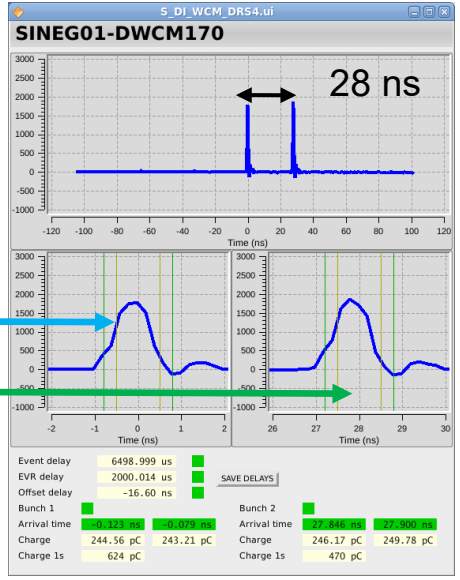
- **Custom pulsed optical links:**
  - Will affect many systems (BAMs, lasers and infrastructure in SK.023)
  - Suffers from staff shortage - *we try* to make progress in parallel despite the difficult situation!

Outlook: The system needs to be upgraded!

- Scalability! Number of clients significantly increases, especially lasers. User requirements increase.
- Needs planning well in advance, *especially pulsed optical links.*
- All implementations require shutdown time.
- Critical spare part situation for several components! Evaluation of new reference laser oscillator ongoing… Many spare parts require external person power (companies…)

Gun laser systems – status





- We have now a **well-established and reliable photo-cathode laser facility**
- The **Mizar UV stretcher** was installed and commissioned
- The **Jaguar** is **decommissioned** (January 2022)

(Alexandre Trisorio et al.)

Publications 2021:

- S. Bettoni et al., *Overview of SwissFEL dual-photocathode laser capabilities and perspectives for exotic FEL modes*, High Power Laser Science and Engineering 9, e51 (2021)
- C. Vicario et al., *Two-color x-ray free-electron laser by photocathode laser emittance spoiler*, Phys. Rev. Accel. Beams 24, 060703 (2021)

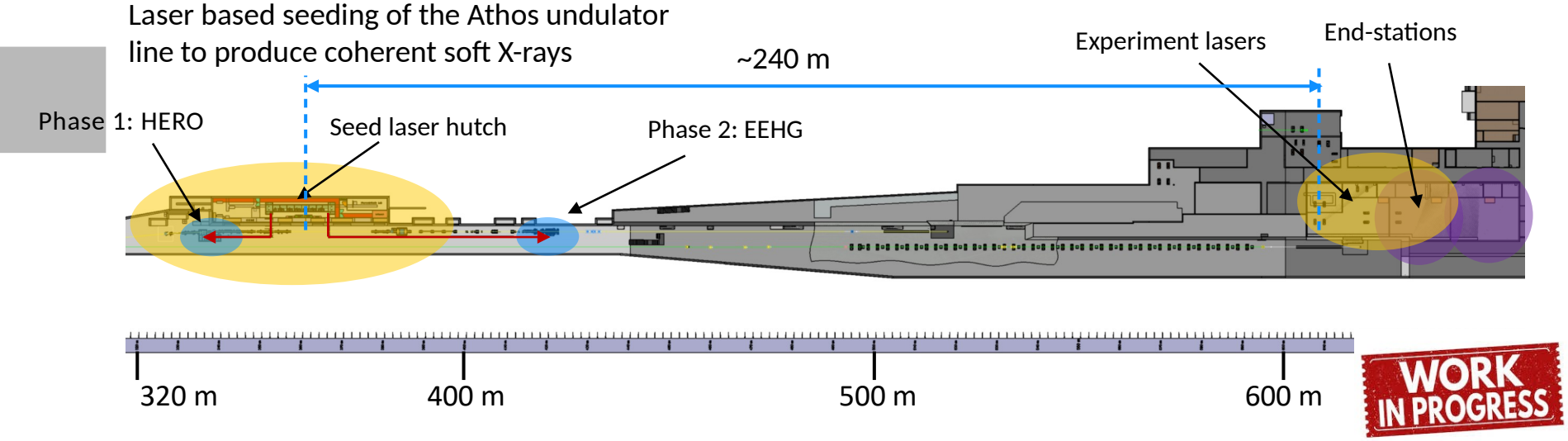
(Alexandre Trisorio et al.)

Gun laser systems – plans & open issues

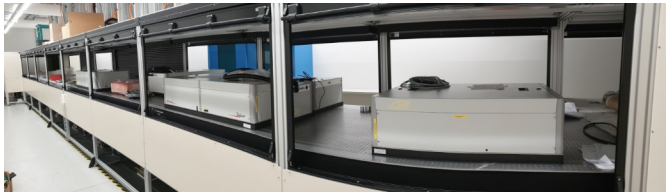
- **Time resolved, high resolution UV pulse energy measurement device:** prototype expected this year.
- **Predictive feedback:** collaborative work with Inspire AG and FH Brugg for implementing and evaluating performance of predictive feedbacks instead of the 'classic' approach.
- **Replacement of low-phase-noise laser oscillators at 1040/1550 nm:** NKT Photonics will no longer provide/support them in the future!
  - We have to find a new industrial provider / make our in-house development of laser oscillators at 1040/1550 nm for the gun lasers and T&S
  - Strategic project for SwissFEL, discussions started between the T&S group, the gun laser group and potential industrial partners. Finance and manpower will be required.
- **Optimization of gun laser beam position on the cathode is required** to optimize the FEL pulse energy
  - We did not identify the exact cause of that (laser related or not). However there is a lack of time for deeply inquiring and discriminate between all possible sources.
  - Workaround solution: optimizing FEL energy by moving the gun laser beam position onto the cathode (approx. once every machine setup shift).

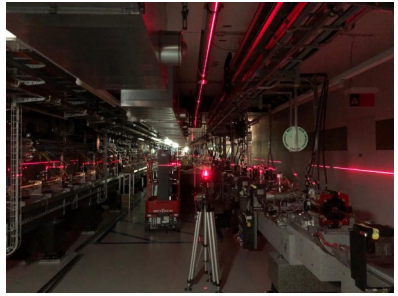
Seed laser systems (Athos) – work in progress

Laser based seeding of the Athos undulator line to produce coherent soft X-rays



Laser setup commissioned for 1st test of slicing by end of June 2022

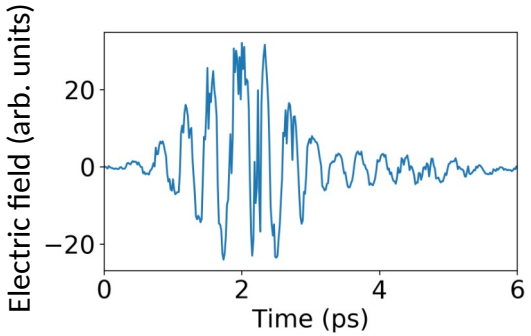


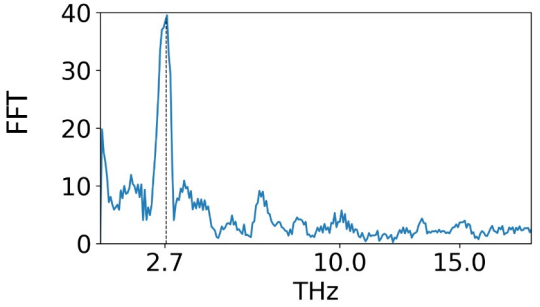


Pump laser systems – Aramis

(Steve Johnson et al.)

- Consistent **support of ongoing user experiments** using pump lasers
- Delivery of **tunable nanosecond beam** to Alvra for user experiments
- **~15 fs pump pulse duration** for experiments @ Alvra demonstrated
  - Integrated with timing tool, ~40 fs time resolution (likely limited by cross correlation response)
  - Future: improve time resolution to pump limit
- **Phase-stable mid-IR development**
  - **Tunability extended down to 2.7 THz** (max. is about 20 THz)
  - First phase stability measurements
  - Future: improve phase stability / feedback





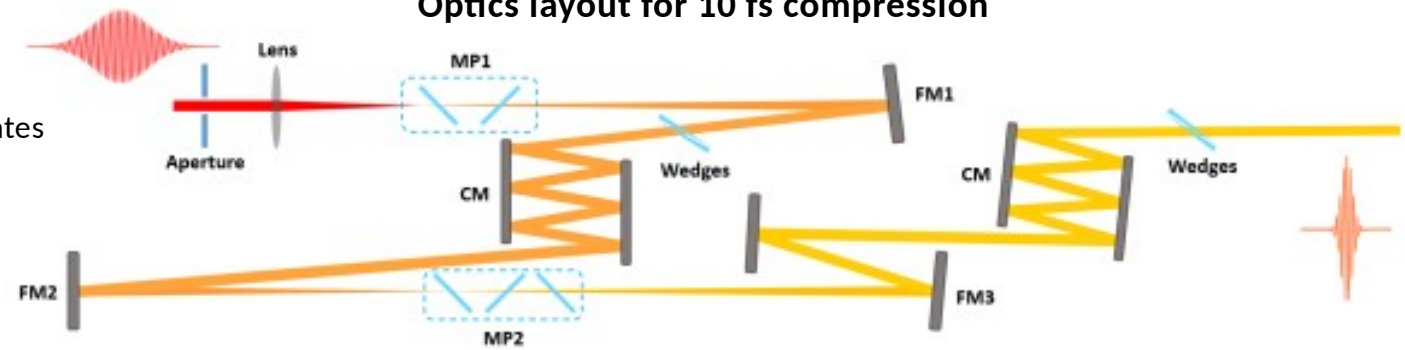
Pump laser systems – Athos

(Steve Johnson et al.)

- **Main laser system installed & commissioned**
- **Beam transport installed & commissioned**
- Timing tests revealed **issues connected to "power track" feedback,** able to minimize to get **~60 fs (fwhm) / 25 fs (rms) short term jitter** (still longer term issues)
- **Safety system tested and working now**
- **High-field single-cycle THz source** built and tested, still needs to be commissioned at endstations
- **New pulse compression scheme** implemented and tested for ~10 fs pump pulse duration

MP = multiple fused silica plates
FM = focussing mirror
CM = chirped mirror

Optics layout for 10 fs compression



Xie, Deng & Johnson, High Power Laser Sci. Eng. 9, 2021

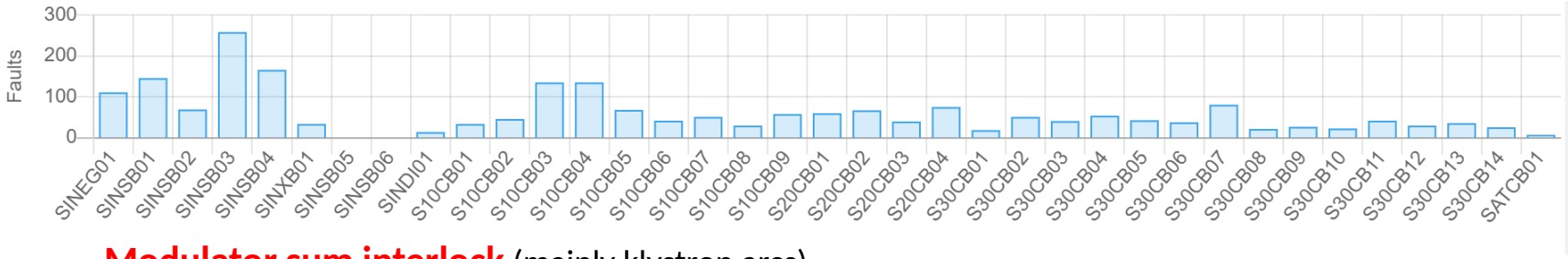
RF systems: fault analysis 2021

(P. Craievich et al.)

Overall RF trips

Injector (6 RF stations)
798 global trips = 3.3 trips/station/week

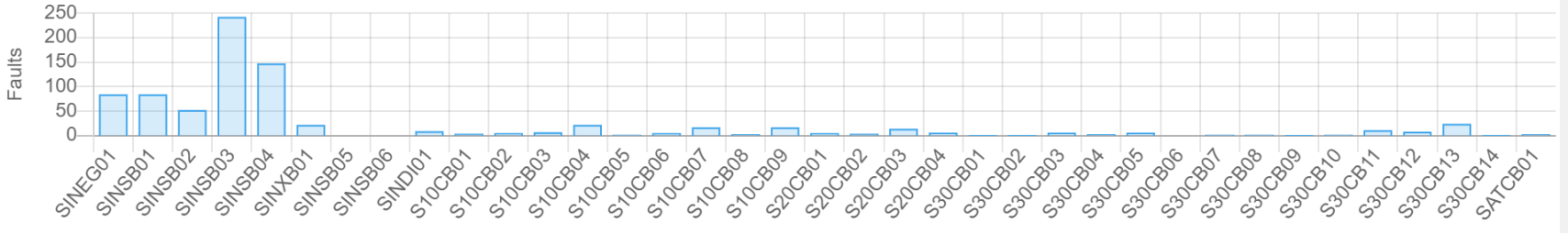
C-Band linacs (26 RF stations)
1381 global trips = 1.3 trips/station/week



Modulator sum interlock (mainly klystron arcs)

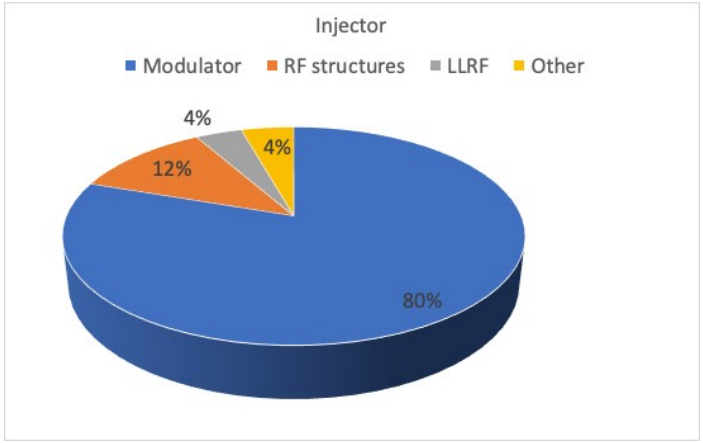
Injector (6 RF stations)
640 trips = 2.7 trips/station/week

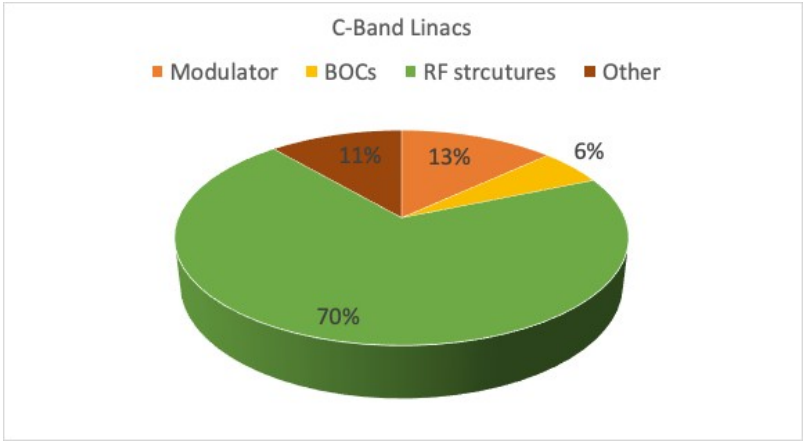
C-Band linacs (26 RF stations)
182 trips = 0.2 trips/station/week

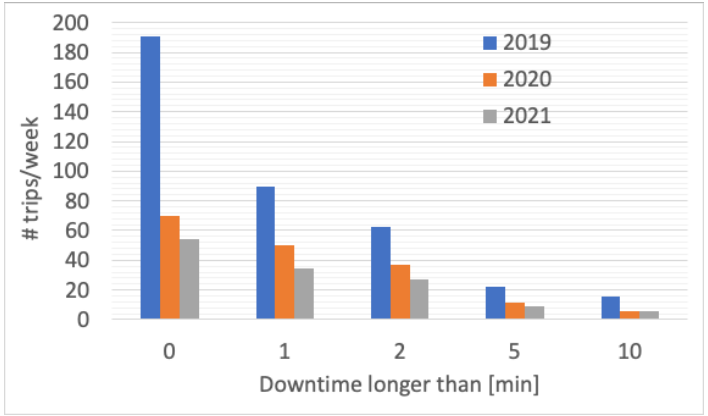


RF systems: fault analysis 2021

(P. Craievich et al.)







- RF faults in the injector are mainly due to klystrons arcs (modulator).
- RF faults in the C-band linacs are mainly due to RF breakdowns
- Only little improvement in the number of RF faults and their duration from 2020 to 2021

RF systems in 2021

(P. Craievich et al.)

General comments

- The basic **training of on-call personnel** has been completed but more in-depth training is needed.
- RF personnel also did some **shifts in MD weeks** to improve the RF linac performances (stability, 2-bunch operation, klystron measurements)
- Positive experience with **Wednesday startups after shutdowns**
- **Official communication channel** with operation is the **RF master operation panel.** The **RF WebEx chat** is an informal channel mainly for internal RF communications but also works with operation
- **CPI-refurbished Thales klystron in station SINSB02 performed well** (40 MW, operation at 35 MW) – good news!
- **Replacement of the klystrons in S10CB07 and S30CB12 went smoothly.** In any case we need time for the conditioning during the startup.

Issues

- Second **CPI-refurbished Thales klystron installed in SINSB03** had a **serious filament problem** and had to be replaced with an old (non-refurbished) one.
- **SINSB03/04 klystron arcing.** Sometimes strong effect on operations. Both stations to receive either CPI-refurbished Thales klystrons or new Canon klystrons (to be decided…).
- **SINDI01 (low energy TDS): modulator problems with HV connections** (ageing). Solution for now is to run at lower voltage unless when needed to slow down ageing. (Exact operation procedure to be defined.)
- **C-band RF phase jitters due to "multipacting effects" in the klystrons and BOCS:** good region in the klystron is moving and sometimes difficult to follow. In the BOC RF power must be >40 MW to avoid multipacting.
- **SATCB01: operation only at limited energy gain** (180 MeV) due to RF conditioning issues (see next slide).

RF systems in 2022+

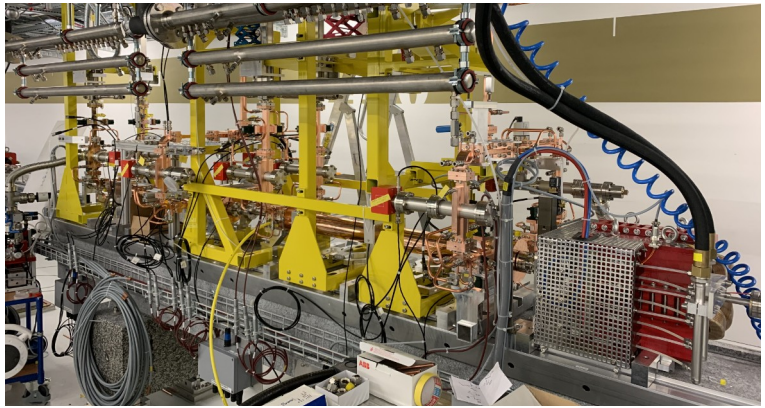
(P. Craievich et al.)

General plan

- **Klystron replacement strategy in the injector:** refurbished klystrons from CPI and new Canon klystron. In April shutdown the first Canon klystron will be installed in SINSB04. Gradual replacement of all S-Band Klystrons with Canon (SINSB03/04) and CPI-refurbished (SINSB01/02) klystrons.
- Mid-, long-term: **Modulator renewal project for the injector.** Starting after the X-band TDS project.
- **C-band linac klystron replacements:** preparing a long-term plan for systematic, regular replacements.
- **SATCB01 (Athos linac):** Due to the frequent arcs while conditioning the waveguide systems, inspection of the waveguide components in April shutdown and possibly replacement of the klystron. In the meantime we are ordering two full waveguide networks from MHI.

X-band Deflecting Cavity (SATMA02)

- Waveguide network and RF structures installed and ready in the tunnel.
- Commissioning of the HV modulator started end of 2021.
- **Goal:** Klystron connected to the waveguide in the April shutdown and with RF conditioning following (first streaking not earlier than after one month, at limited deflection voltage).



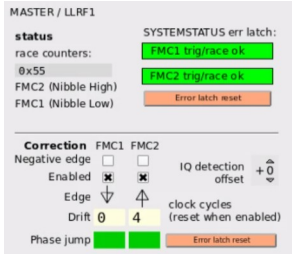
Low-Level RF – achievements 2021

(Z. Geng, R. Kalt)

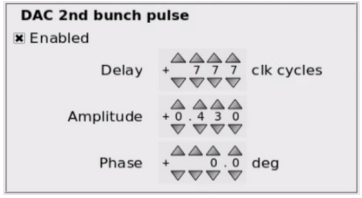
Achievements

- **SATCB01** in beam operation
- **SATMA02** (X-band TDS) in progress
- **C-band RF measurement stability improved** (LO amplifier exchange)
- LLRF **trigger-clock racing problem** solved
- Robust and fast two-bunch OP support in firmware
- LLRF data reduction implemented
- Klystron frequency response measurement tool
- RF-beam jitter correlation on-line tool

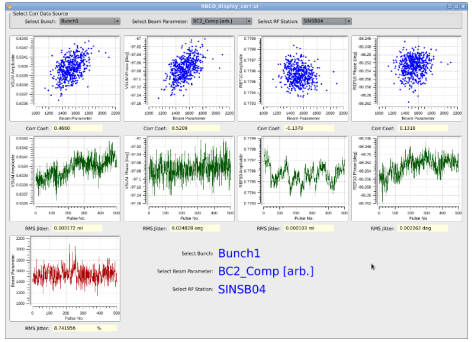
X-band frontend



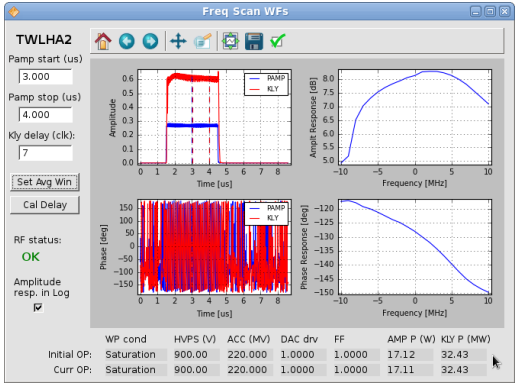
Trigger race handling



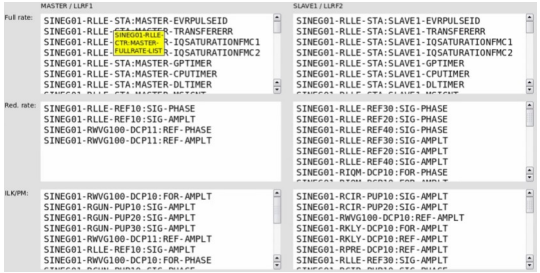
Firmware 2-bunch support



RF beam jitter correlation



Klystron frequency response measurement



Data reduction

Low-Level RF – issues and plans 2022

(Z. Geng, R. Kalt)

Issues

- **Drift of gun** (SINEG01) – very sensitive for lasing
- **Beam energy drift in linac-2/3** (under investigation, multiple systems involved)
- Robustness of software in case of abnormal situations (e.g., network overloading)
- Some loose RF cables – can cause high RF jitter (regular verifications can help to avoid this issue)
- Some hardware failures (e.g., power supplies)

Plans 2022

- Prepare **SATMA02** (X-band TDS) for startup
- **SINXB01 RF front-end upgrade** to new design
- Upgrade of the **RF front-end interface firmware**
- Upgrade of the RF fault statistics tool
- Continue consolidating LLRF software / firmware
- Drift study and mitigation (RF gun and linacs)

(M. Paraliev)

Resonant kicker and septum

Achievements

- Running routinely with <5 ppm amplitude stability, only one HW problem in 2021!
- Switched to global timing event “Generic 100 Hz” to reduce number of dedicated events.
- Measures implemented to disable the “Frequency feedback” (Kickers auto-tuning) in case there is suspicion that the relative encoders have lost position due to power cycle.
  - Long term goal: A solution with absolute encoders will get rid of the necessity to home RKs’ tuners after stepper motor controller power cycle.

In Progress

- **Interlock of RKs’ electronics cooling water** is implemented using a flow-switch. Monitoring the cooling water pressure is in progress. Pressure transducers are already installed but have to be connected to EPICS.
- Flow-switch is not sensitive enough to detect a single cooling circuit failure.
  - Goal: Analyzing the pressure drop over the water distribution circuit to generate a warning even if only one (out of four) individual cooling circuit is down.
- Switchyard **RHEL7 migration** is only partially done. The virtual machine for RK feedback SW and the application itself should be prepared and tested.

The cooling water flow-switch that generates the cooling water interlock signal.

Manometers and pressure gauges to measure the pressure drop over the cooling circuit.

Electron beam diagnostics: bunch compression monitors

(G.L. Orlandi)

In normal operation:

- Bunch compression monitor at BC1 (SINBC02-DBCM410)
- Coherent diffraction radiation monitor at BC2 (S10MA01-DCDR080)
- Bunch compression monitor in Aramis energy collimator (SARMA01-DBCM030)

New monitors under construction, to cover the full range of machine operation modes:

- **Coherent diffraction monitor in Athos switchyard (SATSY03-DCDR050)**
- **Coherent diffraction monitor in Aramis energy collimator (SARCL01-DCDR105)** (complementary to BCM)
- Both monitors to be used in beam feedbacks
- Construction status (both monitors):
  - Already installed/functional: in-vacuum hardware (pneumatic feedthrough & DR screen), optical hardware, detector aligned and installed; cables from racks to tunnel; MPS interface ready
  - Still missing: Control electronics (filters, pneumatics, pyro-detector, MPS connection); Beckhoff DAQ&Motion system (drivers 2 motors focusing mirror, pyro-signal acquisition), EPICS (signal integration & control panel)
- Setup and commissioning time plan:
  - SATSY03: Final installation/pre-beam check: April ‘22 and August ‘22, beam commissioning fall/winter ‘22
  - SARCL01: task request to be submitted by EBI-Group to AEK; final installation/pre-beam check in Dec. ‘22, beam commissioning in ‘23? (Depending on AEK-EBI decision!)

Electron beam diagnostics: beam loss monitors

(G.L. Orlandi)

Beam loss monitors (BLMs), longitudinal loss monitors (LLM), dose rate monitors (DRM)

- In normal operation.
- Regular firmware upgrades and maintenance during machine shutdowns.

Athos BLM upgrade

- Financial resources for upgrade allocated in budget 2022
- **14 new BLMs** will be installed in Athos
- BLM positioning in the beam line defined; rack assignment done; all sub-components from beam sensor to the scintillator signal transmission to the rack already ordered on budget 2021 or already on stock
- Kickoff meeting with AEK experts planned in early February to evaluate:
  - sub-systems to be developed: signal amplification and readout electronics, timing, intracrate cabling, EPICS configuration, PV Archiver, Save&Restore, operation interface software configuration etc.
  - Material and sub-component development costs and necessary manpower
  - A time horizon for the final delivery of the system and intermediate temporal milestones
- Task request to be submitted to AEK
- Time scale and intermediate milestones of the delivery of the complete system will be clarified after kickoff meeting and approval of the task request by AEK

Electron beam diagnostics: charge monitors

(G.L. Orlandi)

Charge measurement campaign (2021):

- **Absolute charge measurements** based on the **waveform analysis of the monopole signal of the cavity-BPM:** 10% charge underestimation w.r.t. to reference gun ICT (first Aramis ICT)
- **Alignment of all the charge monitors** (ICT, WCM, BPM) to the charge value determined by the cavity-BPM method (MD shift on 1 Oct. 2021)

Integrating Current Transformers (ICT)

- Charge readout of first and last ICT in Aramis stable on long time scale and both aligned with BPM charge readout
- Two intermediate Aramis ICTs affected by a **long-term scale drift** (±5% variation w.r.t. first ICT)
- Firmware updated with code recording the cumulative charge integration shot-to-shot (BAG issue)
- Firmware upgrade and maintenance normally carried out during the shut-down

Wall Current Monitor (WCM)

- Used for coarse synchronization of photocathode laser timing and RF gun phase
- 2-bunch charge monitoring @100 Hz
- Signal readout electronics: Keysight card presently borrowed from beam line; order of new Keysight card on-going
- **Numerical and experimental characterization of WCM** (summer student work):
  - estimate of the transfer impedance (uncertainty of 5% at least)
  - RF background affects the WCM signal (appropriate fitting of the signal time integration needed)

Electron beam diagnostics: wire scanners and synchrotron radiation monitors

(G.L. Orlandi)

Wire scanners (WSC):

- Functionality and wire integrity regularly checked (wire-fork of S20SY03-DWSC090 replaced in the Dec. 2021 shutdown)
- High-level application (pshell script) for beam profile measurements, integrated with pyscan routine for emittance measurements.
- Alternative approach with EPICS server developed, managed and maintained by beam dynamics for beam profile and emittance measurements. Recently tested (summer student internship).

Synchrotron radiation monitors (SRM):

- Fully non-invasive monitor of the beam profile at the entrance of the third dipole of the chicane
- SRM at BC1 (PCO.Dicam C1 camera): can measure either bunch-1 or bunch-2 at 100 Hz.
  - Conversion of the relevant horizontal beam profile parameters (centroid and rms width) from length unit (µm) to beam energy unit (MeV) in preparation
- SRM at BC2 (sCMOS PCO.Edge camera): measure the 2-bunch superposition at 100 Hz.
- Recommendation from electron diagnostics review panel to use SRM signal as input for machine learning application.

Electron beam diagnostics: beam position monitors

Recurrent activities (2021, 2022,...)

- **Recalibration** of undulator BPM X/Y scaling factors, charge and relative RF phases (at least every 2-3 months):
  - Compensate "normal" long-term drift & aging → reproducible undulator orbit
  - Undulators: Would benefit from more reliable quadrupole mover systems
- Early/proactive **detection of defects.** Example: commercial H&S RF cables showed contact degradation → replacement of all cables planned.

Activities 2021

- **Prototype of new BPM EPICS IOC tested** (Xilinx ZynqUltrascale+ with 64-bit 4-core ARM CPU)
  - Will replace (too) slow IFC1210 VME IOCs
  - Series production delayed due to world-wide component shortage → 2022+
- **Athos undulator BPM hardware:** Preliminary solution ("MBUs" = borrowed Aramis spares) replaced with **final solution** (**"DBPM3"**, based on new SLS2 platform)
- Started **investigation of long-term stability of position and charge readings:**
  - BPMs used for orbit, energy & charge feedback → BPM drift has impact on machine stability
  - Correlated BPM readings with temperature, humidity, ...
- Measurement of charge bunch-to-bunch crosstalk of BPMs (~1%) & ICTs (~11%)
- **BPM charges calibrated** vs. Turbo ICTs after their systematic calibration errors have been reduced
- High-level software development for improved diagnostics & data analysis:
  - GUIs with time-series SVD of position & charge readings to identify jitter/drift sources
  - Analysis & plotting of charge vs. temperature/humidity/... drift coefficients

(B. Keil)

Electron beam diagnostics: beam position monitors

Hardware Upgrades 2022:

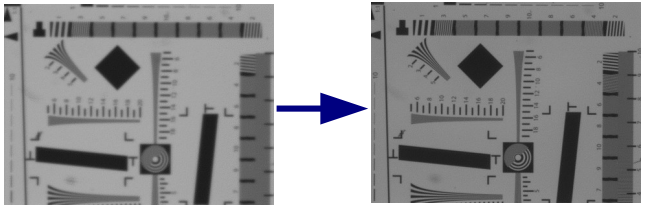
- **Upgrade BPM IOCs** from IFC1210 to Xilinx ZynqUltrascale+ **(no more VME)**
- Replace bad commercial **RF patch cables** in BPM racks
- Improve **temperature stability** of SwissFEL BPM racks by installing regulated heater at bottom of rack
- Install final **fan control** for Athos undulator (DBPM3) BPM electronics → will reduce position/charge drift & improve long-term orbit stability.
- **Upgrade Aramis undulator BPM electronics** (MBU) to newer Athos version (DBPM3)
  - Goal: Same BPM type for all undulator BPMs, easier maintenance
  - Old MBU systems: To be used as long-term spare stock for linac BPMs

Other Activities 2022:

- Digital **reduction of bunch-to-bunch crosstalk** for future modes with (more) different Athos/Aramis charges
- **Simplify/improve maintenance & operation.**
  - Goal: Intelligent automatic low-level software replaces high-level Python scripts (executed manually by experts). Automatic detection & reporting of anomalies, easier change & reporting of operation modes, etc.
- **Collect all BPM data at one central point** via dedicated fiber optics network
  - Preparation for **future fast "real-time" SwissFEL beam feedback**
  - Test SLS2 fast feedback network at SwissFEL
  - Useful for advanced real-time low-level diagnostics at 100 Hz on ZynqU+ (real-time system)
  - BPM data analysis on low-level, result in waveforms (SVD, FFT, ...) for everyone (presently high-level python code for experts, CPU intensive ...).

Electron beam diagnostics: screens

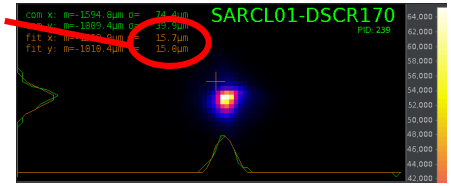
(P. Juranić)

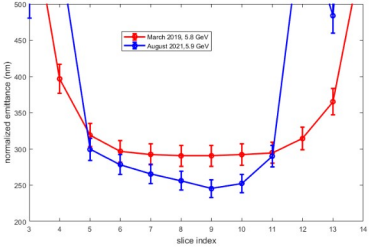


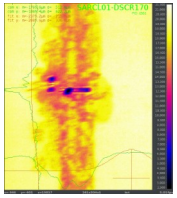
old *new*

Filter upgrades

- Resolution problems with old filters → replace with new ones
- New optics design necessary to focus with new filters
- Much improved resolution! Can measure down to 15 µm
- Much better slice emittance measurement!
- Upgrade priority:
  - **Done:** SARCL01-DSCR170 and SATBD01-DSCR120 (slice and projected emittance measurements at high energy)
  - **To be done (in order of priority):**
    1. SATMA01-DSCR030 (projected emittance measurements at Athos)
    2. S10BD01-DSCR030 (longitudinal phase space measurements at the injector)
    3. SARBD02-DSCR050/SATBD02-DSCR050 (long. phase space meas. after Aramis/Athos undulators)
    4. SARCL02-DSCR280 (long. phase space measurements after BC2).
    5. S10MA01-DSCR090, all in Athos switchyard, S10DI01-DSCR020, SINDI02-DSCR075, etc.

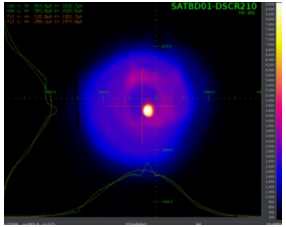


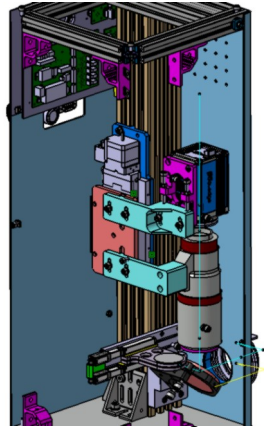




Screen repairs

- SARCL01-DSCR170: replaced damaged Ce:YAG crystal
- SATBD01-DSCR210: damage spotted in December 2021, to be repaired.



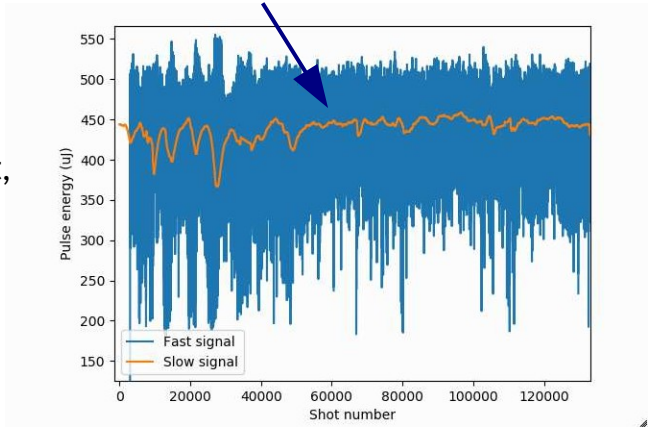


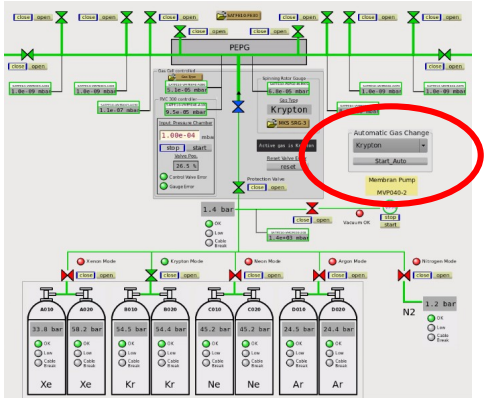
Gas detectors

(P. Juranić)

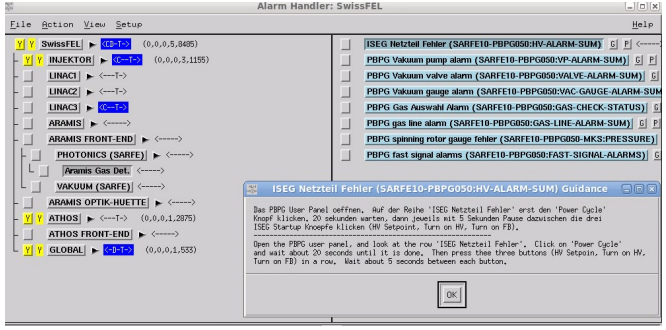
- **Calibration of fast relative signal (HAMP)**
  - Created an algorithm for PBPG with a rolling buffer to define a calibration constant between slow, absolute signal and fast, relative one, and evaluate pulse energy per shot.
  - The evaluation is live, and resets if a key parameter (photon energy, rep rate, etc) is changed.
  - First test successful, but further tests to get to 100% data rate fidelity ongoing. Expect full rollout in 2022.

Calibrated fast signal (blue) follows the slow signal (orange)!





- **Ease of life improvements**
  - Automated gas exchange
  - Alarm handler signals for gas detectors



Undulators – progress and plans

(M. Calvi, Ch. Kittel)

Athos controls interface

- Apple-X modes:
  - **Done: Main polarisations:** planar (LH, LV), circular (C+, C–)
  - **Ongoing:** Elliptical polarisation, successfully tested once (Maloja exp.)
  - **To be done:** Linear rotation, transverse gradient (TGU)
- CHICs:
  - **Done:** Delay, X-offset, phase matching
- Correctors:
  - **Done:** Settings for main polarisations

Aramis progress

- **Done:** Implementation of photon energy scaling via K
- **Ongoing:** Alignment process consolidation
- **Ongoing:** Software tools consolidation

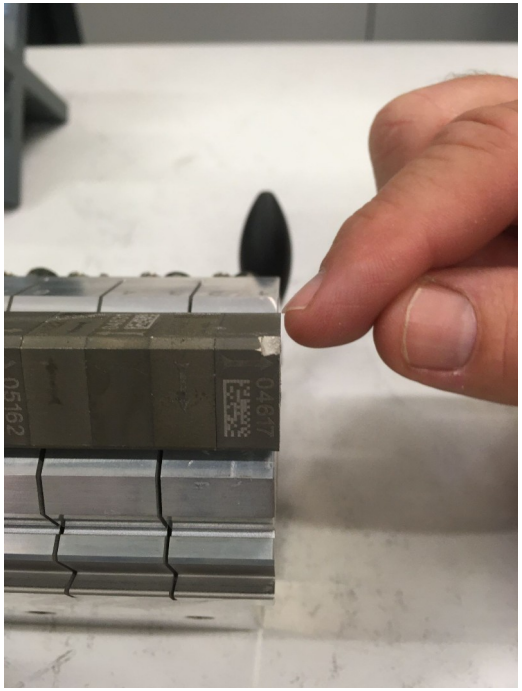
Athos alignment and calibration

- Alignment with spontaneous radiation:
  - **Done:** Filtered by X-ray absorption technique (XAS of Fe, Al)
  - **Ongoing:** Filtered by monochromator
- K calibration with spontaneous radiation:
  - **Ongoing:** Demonstrated in circular pol. (XAS of Fe, Al, C, Si) (need correct foils without holes and better electron-energy tuning [SATCB01 RF station] to be completed)
  - **Ongoing:** Filtered by monochromator in all polarizations
- Alignment with electron beam:
  - **Done:** Orbit corrector polarity checks
  - **Ongoing:** Alignment quadrupole technique

Undulators – issues and remediations

(M. Calvi, Ch. Kittel)

- **Communication issues (Athos):**
  - New wiring within the cabinet, done Jan. 2022
  - Filters ready to be implemented
  - New network connection ready to be implemented
  - More people instructed on Apple-X controls reboot



- **Hardware issues (Athos):**
  - **SATUN19: crumbled magnet** destroys vacuum chamber (Oct. 2021), repaired in following shutdown. Magnetic field profile remeasured and validated.
  - SATUN18: broken cable, replaced in Dec. 2021
  - SATUN22: broken motor, replaced in Jan. 2022
  - **Mover drifts:** Mitigated by auto-disabling the mover motors after 10 minutes (similar to Aramis).
- **Hardware issues (Aramis):**
  - Gap drifts – cause not found, but could be mitigated (setting K value every 10 min.)
  - K value not reached on first attempt (need a second K set).

(T. Celcer et al.)

Controls – infrastructure and service support

Achievements 2021

- **Close firewall** between machine and beamline network (Jan. 2022)
- H1 2021: **take over all Channel Access Gateways (ca-gw)** from AIT, migration of ca-gw's to linux (increased stability)
- Majority of systems **migrated to RHEL7,** including all soft-ioc hosts (finished Jan. 2022)
- Non-functional **optimisation of archiver/image buffer/data buffer service** (separation) to simplify its operation

Plans 2022

- **Channel Access Gateways (ca-gw):**
  - Remaining **issues with image traffic over ca-gw's** → deployed separate ca-gw's handling only image traffic (Jan. 22)
  - Gateway optimisation for images/waveforms, finding **long-term solution**
- Complete **RHEL7 migration.**
- **Removal of AFS** from the infrastructure servers (wherever possible).
- Solving **problems with archiver appliance** on all levels (operation, stability of archiving,…)

Controls – DAQ: backend developments

(T. Celcer et al.)

Collaboration with AWI department

Recording & retrieving of data, detector integration…

Achievements 2021

- **EPICS writer and buffer** ready (to be tested in Q1/2022, recording EPICS data together with BS data – will replace the usage of EPICS archiver for this purpose)
- Various **functional and non-functional improvements** and integrations into **standard-daq** (details on request)
- **Improvements in data retrieval** performance and developments towards a unified data retrieval interface (details on request)
- Actions taken **towards improvement of DAQ recording** (focus on recording after retrieval tasks are completed)
- **Extension of data analysis pipeline** to cover also non SFX experiments (AWI)
- **Successful experiment** with largest **detector @ max rate (16M @ 100Hz)** in June 2021
  (1 PB raw data, converted/compressed and rounded to photon data)

Plans 2022

- Towards **unification of all buffers and archivers** (not in production in 2022)
- Continue to improve: **live processing performance, feature set, backend service deployment, monitoring and management**

Controls – DAQ: data source developments

(T. Celcer et al.)

Beam-synchronous (BS) data sources, cameras and processing

Achievements 2021

- **Data reduction for RF BS sources** (Network load/throughput ~50 % lower, memory usage, CPU usage drastically decreased)
- Cameras: **Simultaneous operation of 2 cameras on 1 server** (full ROI, 100 Hz) – test system in operation in Maloja
- **Online Image Processing:**
  - **Processing streams** of data possible **on local instances** (includes detectors)
  - **GUI/tool** to control the whole system now available
  - Still observing **some data loss** when processing images from several cameras in parallel (data vol. problem)

Plans 2022

- Deployment (replacement) of **image buffer servers, sf-daqsync servers** (for image processing), and additional Image buffer server (image data volume increase from Photon Science, collab. with AWI)
- **Cameras:**
  - Solve the **mis-tagging issue** inside the Camera IOC – work in progress…
  - Simultaneous operation of 2 cameras on 1 server (full ROI, 100 Hz): evaluation of tagging performance
  - New (after reorganization): evaluation of possibility for migration of camera support to linux (long-term goal)

(T. Celcer et al.)

Controls – EPICS integration and challenges

- **Manpower** for integration is still **spread too thin**
  - **PSD support challenges 2022:** Athos beamline commissioning, Furka, Cristallina (BL + ES), supporting Aramis beamline and operational end stations (Alvra, Bernina, Maloja).
    - Expect things to normalise a bit in H2/2022.
  - **Support for GFA expert groups:** efficiency will be temporarily affected due to section reorganisation and transition of tasks (timelines are expert group dependent).
  - **Prioritisation of projects and tasks** will be needed!

- **EPICS upgrade plans 2022:**
  - Continue testing and migration of SwissFEL IOCs to the EPICS 7 version.

- **Main issues** from controls point of view:
  - **Persisting hardware problems with Delta Tau motion controllers**
  - **More connection issues** after deployment of 802.1X network authentication protocol
    - Seems due to implementation of Delta Tau controllers in combination with strict protocol compliance rules of network switches)
  - Overall **motion support for SwissFEL reduced** due to intensive work on motion developments for SLS 2.0 project…

SwissFEL global issues

(S. Reiche et al.)

Athos issues

SwissFEL issues

Strong Orbit Coupling in Athos
- Kick in one plane gives oscillation in the other plane.
- Origin unknown (QFF magnets?)

→ Setup and matching very difficult!
→ Short-pulse high-power mode degraded!

Aperture Limitation in Athos Beamline
- Effective aperture estimated to be 2 mm rather than the 5 mm of the design!

→ Beam and dark current losses.
→ Majority of Athos modes strongly affected!
→ Limited pointing flexibility

Dark Current Limitation
- Too much dark current from the gun
- Well collimated in Aramis (linac-3)
- Not collimated in Athos! (Cannot use dechirpers as foreseen…)

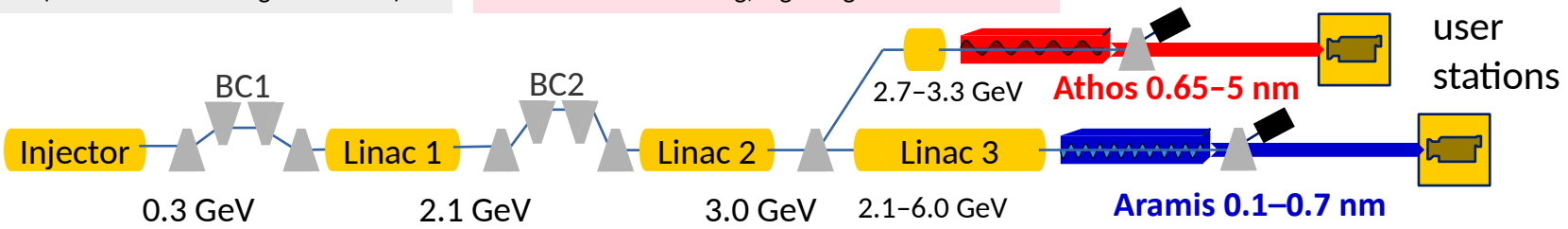
→ Losses even without beam!
→ Focusing-free optics impossible! (needed for ultra-large BW mode)

Dechirpers in Athos Beamline
- Cannot be set to design values without triggering radiation alarms (from halo and dark current).

→ Dechirping function severely limited! (Also collimating function!)
→ Larger FEL bandwidth!
→ Affects EEHG seeding, high-brightness SASE etc.

Missing Instrumentation in Athos
- Not enough beam-loss monitors (BLMs) in undulator line.
- Still missing or broken: one dechirper, wire scanner before switch-yard, X-band TDC…

→ Beam setup more difficult than necessary!



Large Beam Energy Spread (Injector)
- Energy spread much larger than expected.
- Likely culprits are intrabeam scattering and low-gain microbunching – both depend on the distance between source and first compression.

→ Prevents more FEL power and shorter pulses in Aramis.
→ Affects HERO and EEHG seeding.

Beam Current Profile Shaping with Collimation
- Pronounced “horns” in beam current profile have negative impact on beam quality in both beamlines. (Head and tail receive less dechirping than center, thus get overcompressed)
- Collimation at BC1 possible (and proven in MD shifts), but requires more shielding around BC1.

→ Broader SASE spectrum!
→ Setup and operation hampered (beam monitors are sensitive to horns)!

(R. Ganter et al.)

Mitigation of Athos issues

Measures taken or planned to improve the situation for Athos:

- **Athos aperture limitations**
  - Increase aperture by mounting **vacuum valves directly on movable quad tables** – **done** (Nov. 21)
  - Temporary **removal of beam arrival time monitor** (8 mm aperture) near Athos beam dump (monitor not used yet, waiting for electronics) – **done** (Nov. 21)
  - **Beam-based alignment** to compensate for stray fields – **done**
- **Athos losses general**
  - Increase **dose rate limits** in Athos – **done** (Jan. 22)
    - New daily radiation budget for Athos undulators now at 0.1 Gy (was 0.02 Gy like in Aramis)
    - SmCo (Athos) much more radiation hard than NdFeB (Aramis)
  - Additional **beam loss monitors** in Athos undulator line – **in preparation** (see slide on BLM plans)
    - 14 new BLMs in the Athos undulator line to be installed in 2022/23
- **Orbit coupling in Athos**
  - Under investigation (MD shifts with high priority)

Mitigation of SwissFEL issues

Measures taken or planned to improve the situation in SwissFEL in general:

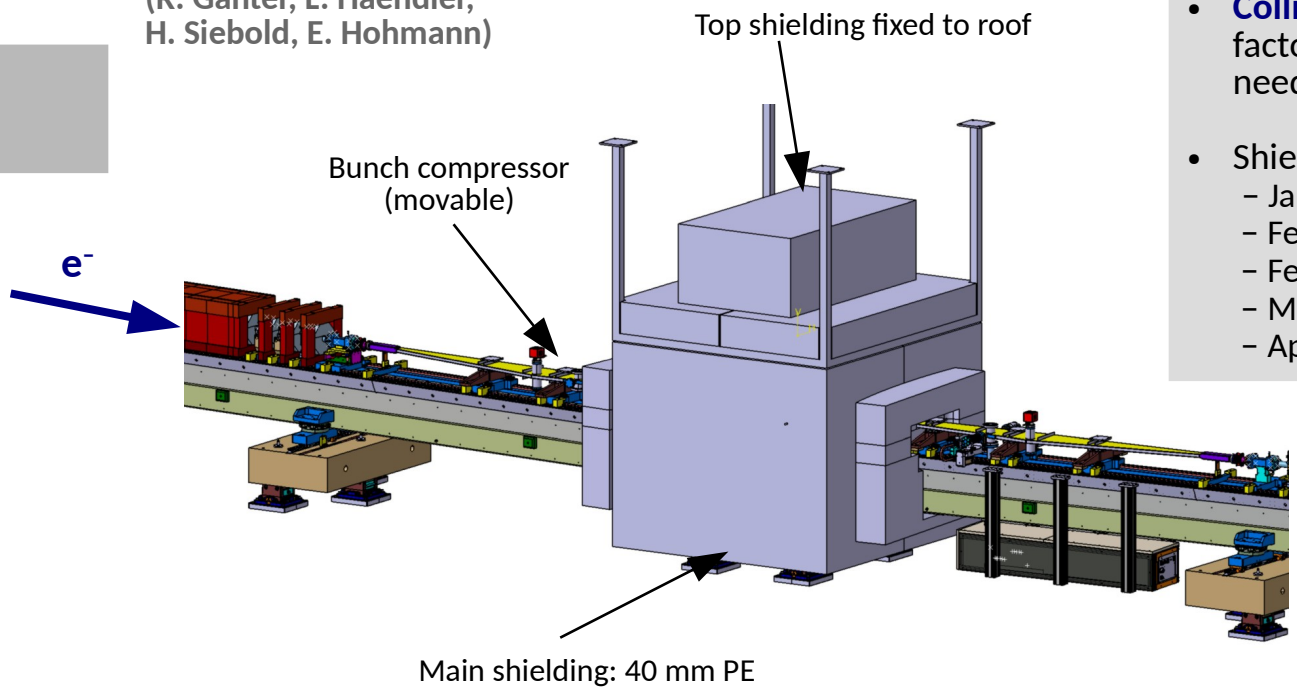
- **Dark current**
  - Additional collimators in the gun area, linac-1, switchyard – **to be evaluated**
  - See what head-tail collimation brings (next point)

- **Head-tail current spikes**
  - Collimation of bunch head and tail at BC1 – **in preparation**
    - Demonstrated in machine development shift
    - Needs massive shielding around BC1 for regular 100 Hz operation
    - Installation of shielding box planned for April ‘22 shutdown
    - BAG/FOPH will be informed in February meeting

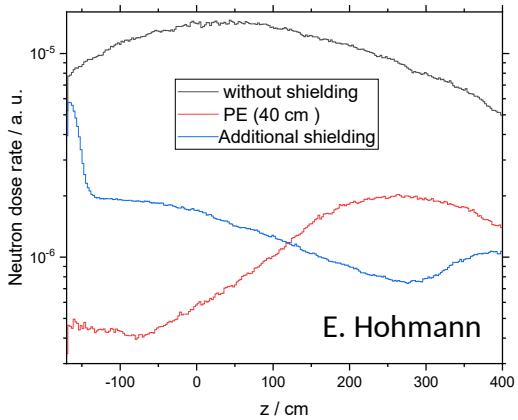
- **Reduction of energy spread**
  - Requires upstream relocation of BC1
  - Major machine modification – perhaps in the context of Porthos upgrade or pre-project?

BC1 shielding to enable head-tail collimation

(R. Ganter, L. Haendler, H. Siebold, E. Hohmann)



- **Collimator (Cu)** already exists, but factor 8 reduction of radiation is needed for 100 Hz operation!
- Shielding **time schedule** (R. Ganter):
  - Jan. 22: raw material ordering (PE)
  - Feb. 22: Detailed drawings
  - Feb. 22: MCNP simulations (V. Talanov)
  - March 22: Manufacturing (PSI)
  - April 22: Installation in tunnel



The lower level…

- Not covered here: **basic infrastructure (electricity, cooling, network etc.).**
- Increasing complexity of our systems puts more load also on the underlying infrastructure…
  - Power and network outages seem to become more frequent.
  - They are very hard to diagnose for operations (relevant diagnostics are also affected!)

- We can help to reduce the complexity of electrical installations by careful, well-in-advance planning!
  - Emmanuel Hüsler: *"The problem is that in the past year, too many planned installations (or cable lists) at SwissFEL were changed at the last minute. While I am used to such last minute changes at PSI, the situation is becoming catastrophic and too much time is lost because cabling has to be remade due to components position changes or type changes. Please increase the reliability of our device lists, installation plans and priorities!"*

Summary (of 10 summaries…)

- **Many improvements,** small and large, increase the **reliability and reproducibility** of SwissFEL!
  - Much appreciated by operations, beam dynamics, and, of course, the users!
- Some critical hardware components (specially from the SwissFEL injector test facility) are showing **signs of ageing** and need to be replaced (e.g. injector RF, including TDS, spare gun laser).
- **Collaboration with industry** often **challenging:** providers are bought up by larger companies or disappear from the market, global shortage of electronic components etc.
- Some groups are **critically understaffed.**
- **Increased complexity** of our facility (more beamlines, upgrades, changes) poses a risk for some systems if they are not upgraded accordingly (e.g. Timing & Synchronization, basic infrastructure)

→ we need to make sure SwissFEL is growing in a coordinated way!

Thank you for your attention!

Thank you for providing slides/info:

- **Cezary Sydlo**
- **Alexandre Trisorio**
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- **Gian Luca Orlandi**
- **Boris Keil**
- **Pavle Juranić**
- **Marco Calvi**
- **Christoph Kittel**
- **Tine Celcer**
- **Sven Reiche**
- **Romain Ganter**