




Florian Löhl & Simona Bettoni :: Paul Scherrer Institut

# Machine overview: Achievements 2020 and objectives 2021

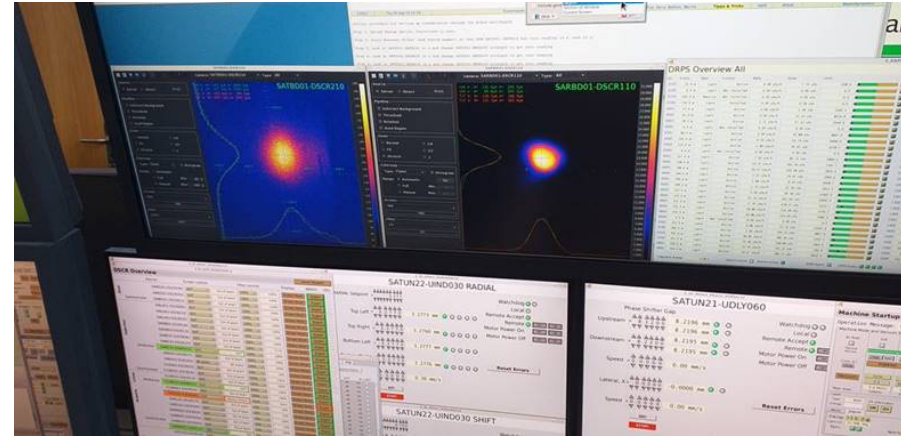
3<sup>rd</sup> SwissFEL Performance Workshop, 27.01.2021, Virtual Meeting

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- A solid grey square is positioned on the left side of the slide, partially overlapping the list of bullet points.
- Selected highlights 2020
  - Observed difficulties
  - Objectives 2021

# Starting point 2020 – the beginning of a new beam line

## Athos Dec. 2019

- First electron beam transport through new Athos line
- Only 2 undulators installed
- First lasing demonstrated using optical klystron mode



## Aramis Dec 2019

- First year of operation at 'nominal' machine parameters
- Experiments limited to 25/50 Hz
- Machine performance had ups and downs in 2019

# SwissFEL during first Corona lock-down

- **Machine operation was stopped on March 17, 2020**
  - Extended shutdown from March 17 till April 27
- **Shutdown tasks were coordinated in a way that only one person was working in a certain area of the tunnel / technical gallery at a time**
- **Re-start of SwissFEL mainly remotely**
  - Restart of RF: April 27
  - Restart of beam: May 4
  - Separate computer with WebEx in control room to allow for communication between external experts and operators
  - Only minimum amount of people on site
  - Initially, beam operation only during the week, from end of May on also during the weekend



## **FEL beam start-ups now coordinated by Simona Bettoni**

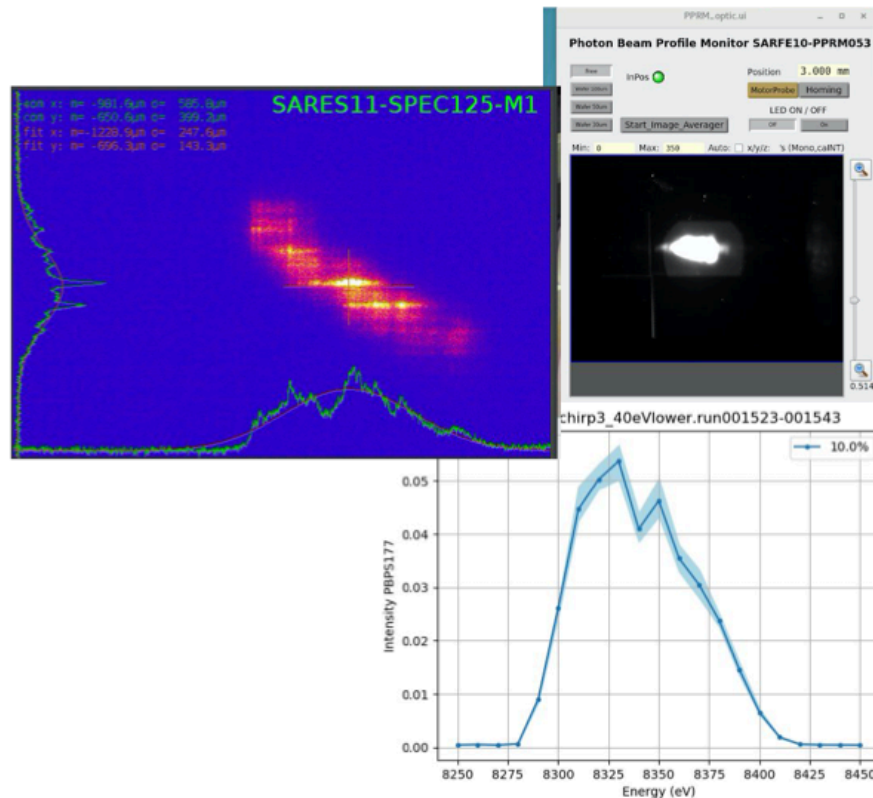
- Starting with 'Corona start-up' in May 2020
- First start-up went very smoothly given the difficult Corona configuration
- Many thanks to all involved experts for their support during this difficult time!

**Simona Bettoni is deputy machine coordinator as of September 2020.**

## Demonstration of new FEL mode: spatially tilted large band-width mode (June 2020)

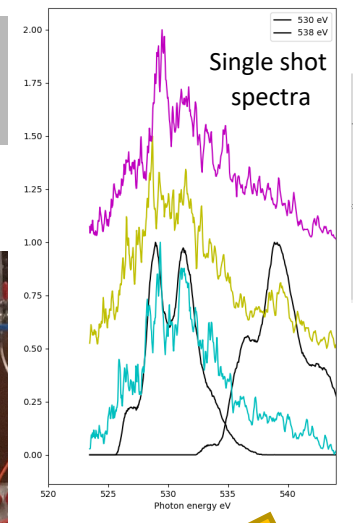
### Goal: single-shot XAS on transition metals

- Very good success in a first pilot experiment

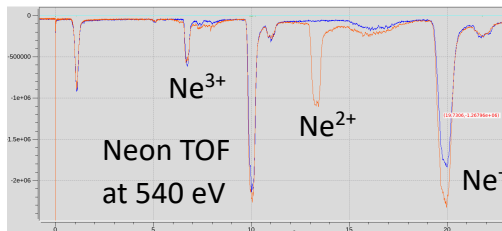


# Selected highlights: First light in Maloja on June 26

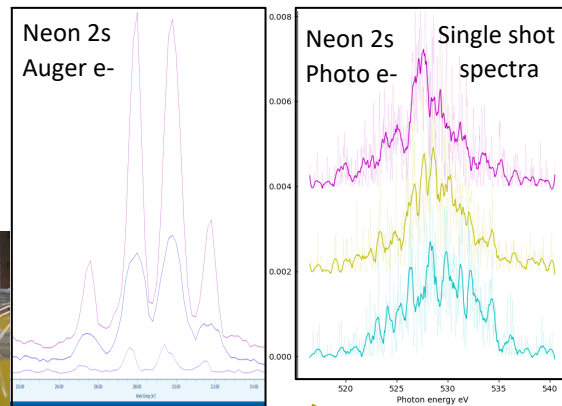
Photon spectrometer



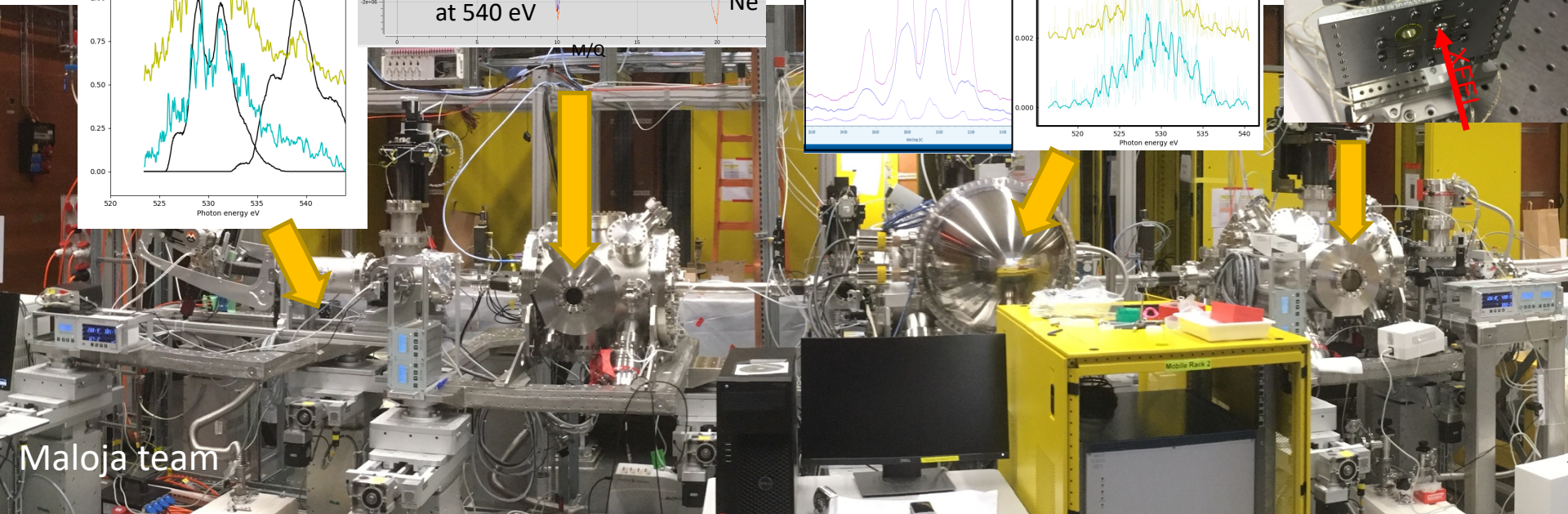
Ion Time-of-Flight  
(TOF) spectrometer



Electron analyzer

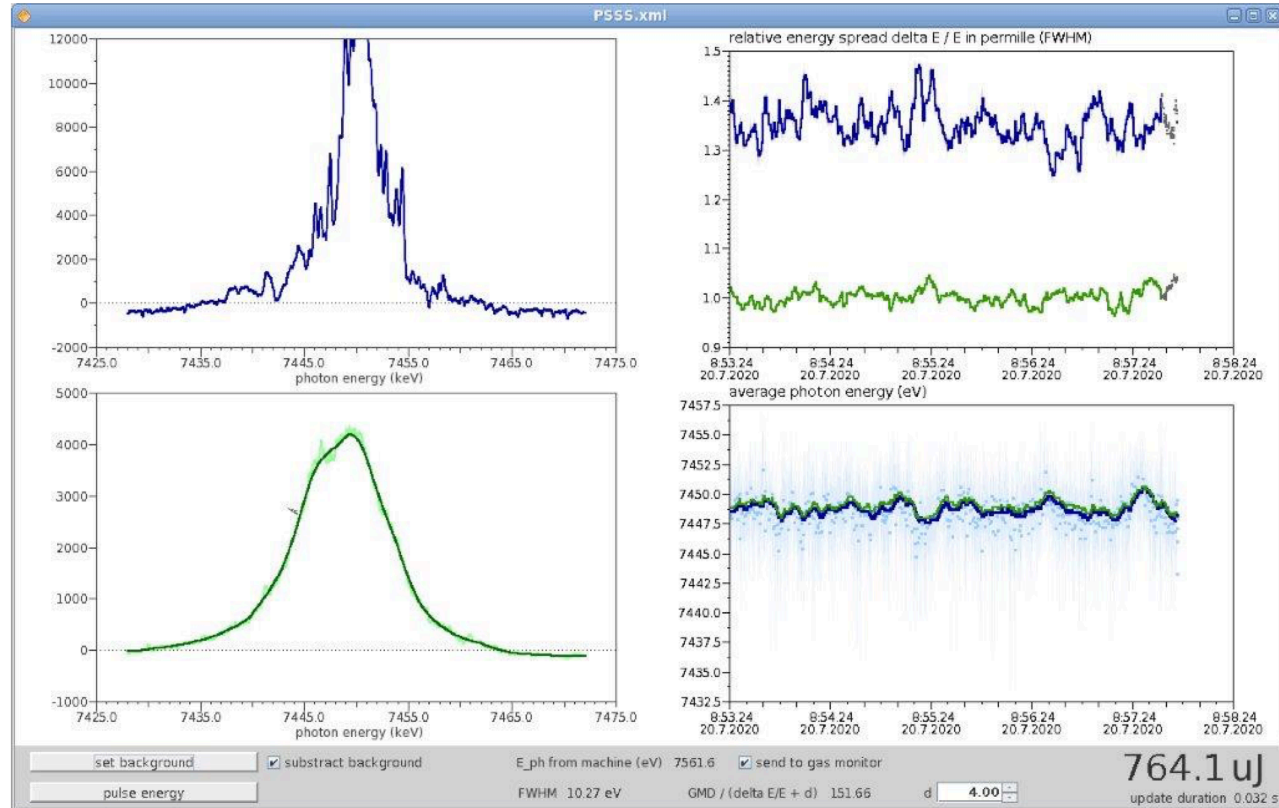


Beam manipulation  
and zone plates



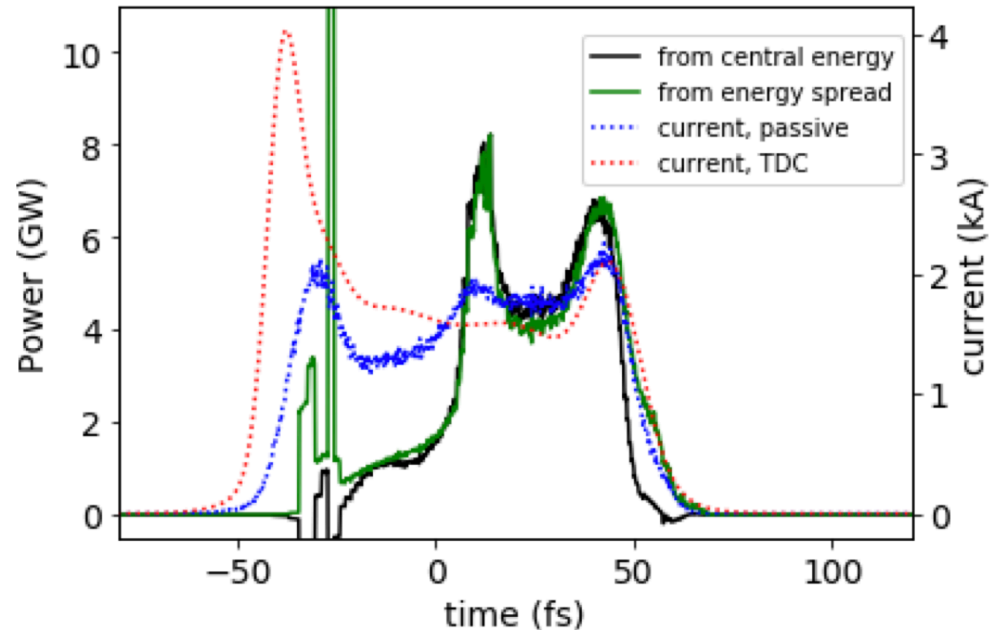
## Narrow bandwidth operation of SwissFEL in SASE mode at record-high pulse energies (July 2020)

- Spectral width:  $\sim 0.1\%$
- Pulse energies  $> 700 \mu\text{J}$



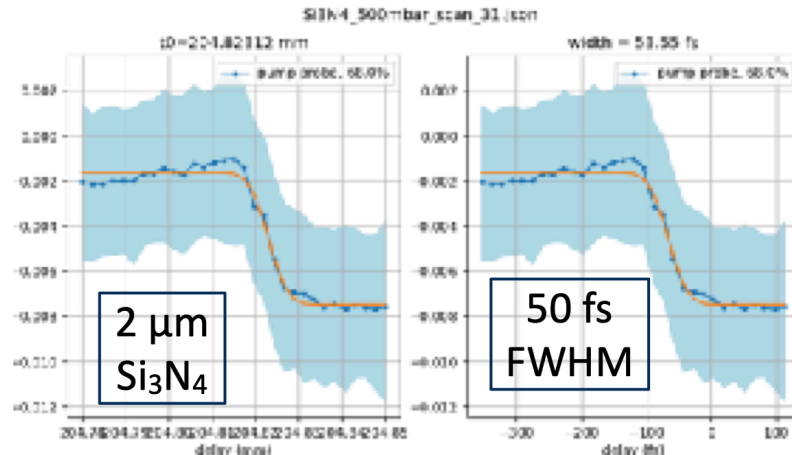
## Streaking of electron beam using corrugated structure

- Allows for reconstruction of FEL temporal profile
- Very high temporal resolution
- Not yet an on-line diagnostics (limited by beam losses)



## Low timing jitter

- Managed to improve timing jitter between FEL beam and pump-probe laser to 20 fs (rms) level!
- Established shorter x-ray pulse operation
- Allowed Alvrá team to achieve new ultra-fast measurement record at SwissFEL of 50 fs FWHM.



from Alvrá team

## **First experiments at 100 Hz in Aramis**

- Data acquisition system (DAQ) had difficulties before processing experiment data at full 100 Hz rate  
→ Experiments were limited to 50 Hz operation
- Major progress on various systems led to first successful experiment at 100 Hz rate! (July 2020)

## **Improved machine start-up**

- Managed for the first time to recover lasing at proper levels in only a few days (August 2020)

## **Managed to make all Aramis undulators contribute to lasing process**

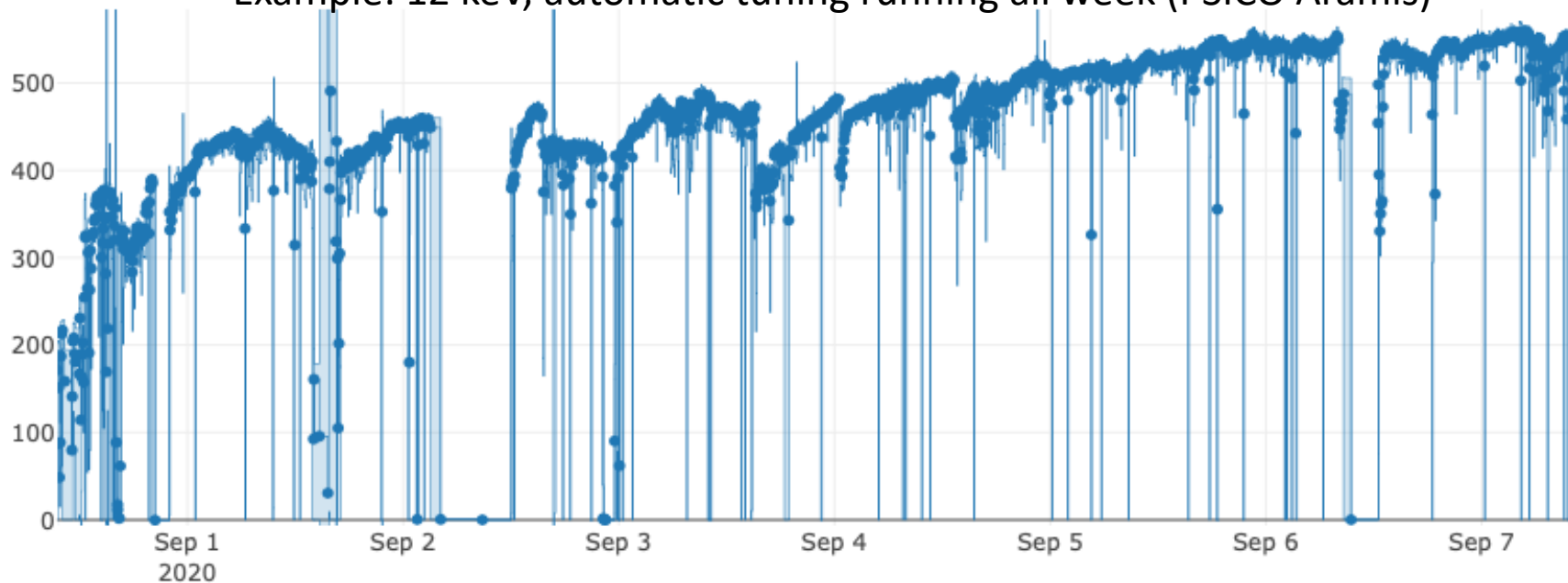
- Before, some undulators did not contribute



## High pulse energies in Aramis

- Pulse energies in 2019 were substantially lower than in 2018
- In 2020, we managed to operate again at record-high levels

Example: 12 keV, automatic tuning running all week (PSICO Aramis)



## **Beam losses in Athos**

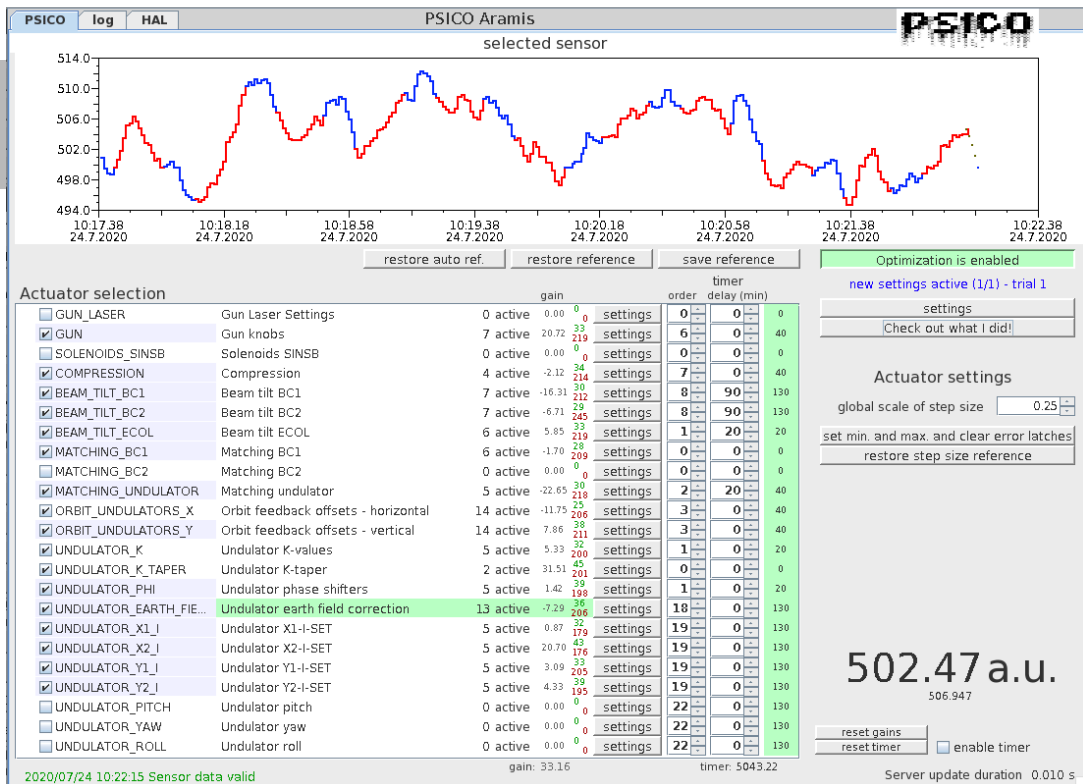
- Situation until end of June, 2020
  - Operation of Athos at rates of even 5 Hz or higher would lead to significant beam loss, especially in the undulator regions
- Managed to reduce beam losses to level at which 100 Hz operation is possible
  - Losses still remain a challenge in the Athos line, but recently improved substantially

## **High pulse energies in Athos**

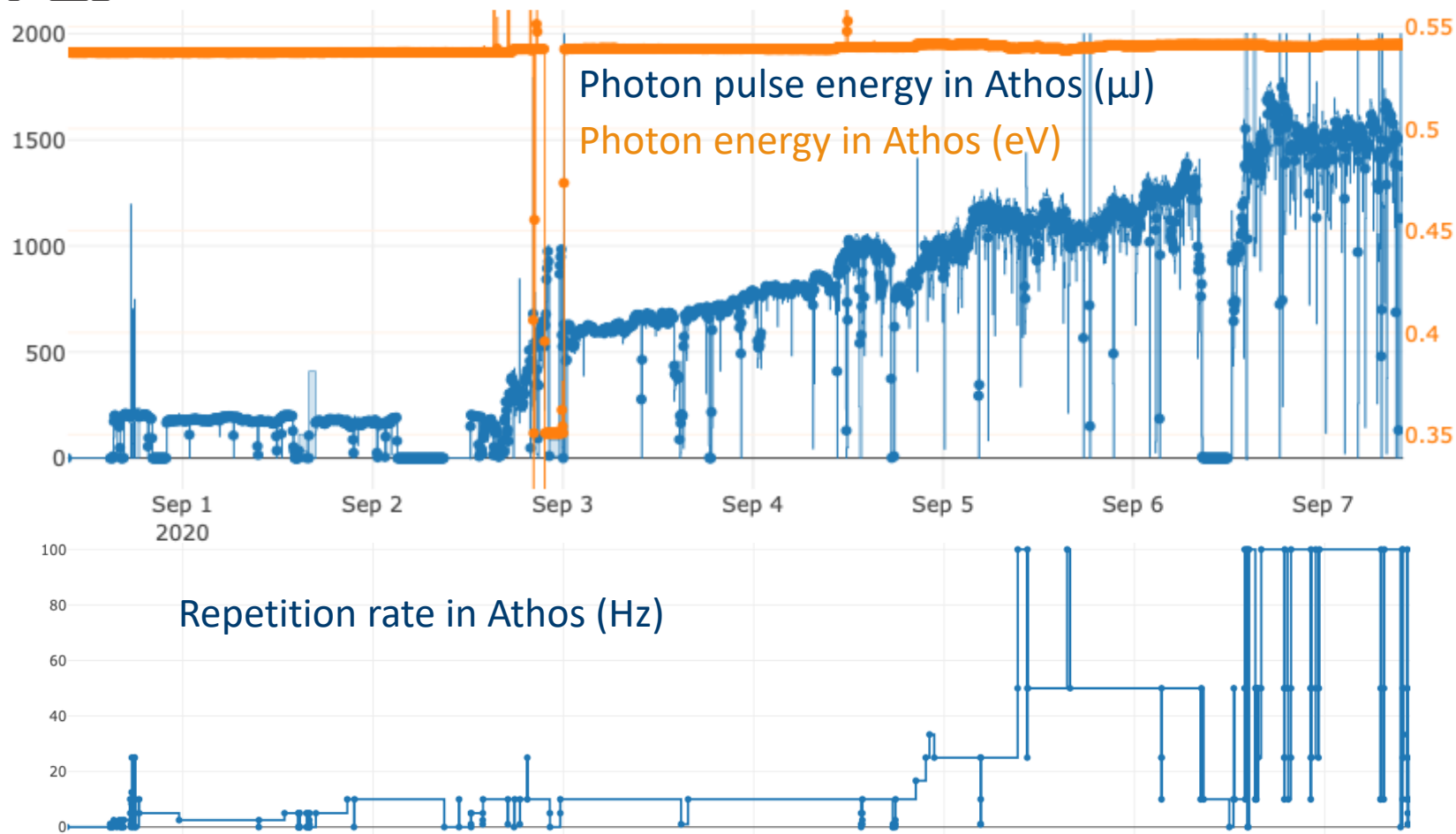
- Managed to achieve around 1.8 mJ@540 eV with only the partial Athos undulator line being installed

## Selected highlights

## Beam loss and FEL tuning using two 'PSICO' optimizers



## Athos photon pulse energy and rate during PSICO tuning



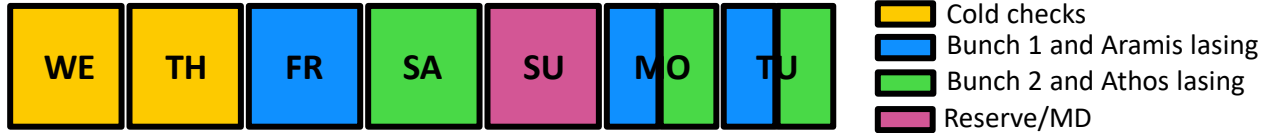
# A compact and cost-effective hard X-ray free-electron laser driven by a high-brightness and low-energy electron beam

Eduard Prat<sup>1</sup>, Rafael Abela<sup>1,6</sup>, Masamitsu Aiba<sup>1</sup>, Arturo Alarcon<sup>1</sup>, Jürgen Alex<sup>1</sup>, Yunieski Arbelo<sup>1</sup>, Christopher Arrell<sup>1</sup>, Vladimir Arsov<sup>1</sup>, Camila Bacellar<sup>1,2</sup>, Carl Beard<sup>1</sup>, Paul Beaud<sup>1</sup>, Simona Bettoni<sup>1</sup>, Roger Biffiger<sup>1</sup>, Markus Bopp<sup>1</sup>, Hans-Heinrich Braun<sup>1</sup>, Marco Calvi<sup>1</sup>, Ariana Cassar<sup>3</sup>, Tine Celcer<sup>1</sup>, Majed Chergui<sup>2</sup>, Pavel Chevtsov<sup>1</sup>, Claudio Cirelli<sup>1</sup>, Alessandro Citterio<sup>1</sup>, Paolo Craievich<sup>1</sup>, Marta Csatari Divall<sup>1</sup>, Andreas Dax<sup>1</sup>, Micha Dehler<sup>1</sup>, Yunpei Deng<sup>1</sup>, Alexander Dietrich<sup>1</sup>, Philipp Dijkstra<sup>1,4</sup>, Roberto Dinapoli<sup>1</sup>, Sladana Dordevic<sup>1</sup>, Simon Ebner<sup>1</sup>, Daniel Engeler<sup>1,3</sup>, Christian Erny<sup>1</sup>, Vincent Esposito<sup>1,5</sup>, Eugenio Ferrari<sup>1</sup>, Uwe Flechsig<sup>1</sup>, Rolf Follath<sup>1</sup>, Franziska Frei<sup>1</sup>, Romain Ganter<sup>1</sup>, Terence Garvey<sup>1</sup>, Zheqiao Geng<sup>1</sup>, Alexandre Gobbo<sup>1</sup>, Christopher Gough<sup>1</sup>, Andreas Hauff<sup>1,7</sup>, Christoph P. Hauri<sup>1,8</sup>, Nicole Hiller<sup>1</sup>, Stephan Hunziker<sup>1,9</sup>, Martin Huppert<sup>1</sup>, Gerhard Ingold<sup>1</sup>, Rasmus Ischebeck<sup>1</sup>, Markus Janousch<sup>1</sup>, Philip J. M. Johnson<sup>1</sup>, Steven L. Johnson<sup>1,4</sup>, Pavle Jurančić<sup>1</sup>, Mario Jurcevic<sup>1</sup>, Maik Kaiser<sup>1</sup>, Roger Kalt<sup>1</sup>, Boris Keil<sup>1</sup>, Daniela Kiselev<sup>1</sup>, Christoph Kittel<sup>1</sup>, Gregor Knopp<sup>1</sup>, Waldemar Koprek<sup>1</sup>, Michael Laznovsky<sup>1</sup>, Henrik T. Lemke<sup>1</sup>, Daniel Llorente Sancho<sup>1</sup>, Florian Löhl<sup>1</sup>, Alexander Malyzhenkov<sup>1</sup>, Giulia Fulvia Mancini<sup>1,2</sup>, Roman Mankowsky<sup>1</sup>, Fabio Marcellini<sup>1</sup>, Goran Marinkovic<sup>1</sup>, Isabelle Martiel<sup>1</sup>, Fabian Märki<sup>1,10</sup>, Christopher J. Milne<sup>1</sup>, Aldo Mozzanica<sup>1</sup>, Karol Nass<sup>1</sup>, Gian Luca Orlandi<sup>1</sup>, Cigdem Ozkan Loch<sup>1</sup>, Martin Paraliev<sup>1</sup>, Bruce Patterson<sup>1</sup>, Luc Patthey<sup>1</sup>, Bill Pedrini<sup>1</sup>, Marco Pedrozzi<sup>1</sup>, Claude Pradervand<sup>1</sup>, Peter Radi<sup>1</sup>, Jean-Yves Raguin<sup>1</sup>, Sophie Redford<sup>1</sup>, Jens Rehanek<sup>1,11</sup>, Sven Reiche<sup>1</sup>, Leonid Rivkin<sup>1</sup>, Albert Romann<sup>1,14</sup>, Leonardo Sala<sup>1</sup>, Mathias Sander<sup>1</sup>, Thomas Schietinger<sup>1</sup>, Thomas Schilcher<sup>1</sup>, Volker Schlott<sup>1</sup>, Thomas Schmidt<sup>1</sup>, Mike Seidel<sup>1</sup>, Markus Stadler<sup>1,12</sup>, Lukas Stingelin<sup>1</sup>, Cristian Svetina<sup>1</sup>, Daniel M. Treyer<sup>1</sup>, Alexandre Trisorio<sup>1</sup>, Carlo Vicario<sup>1</sup>, Didier Voulot<sup>1</sup>, Albin Wrulich<sup>1</sup>, Serhane Zerdane<sup>1</sup> and Elke Zimoch<sup>1</sup>

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# Start-up and setup optimizations

## TIME LINE: MACHINE-PHOTONICS AGREEMENT



+ Startups shifted from Monday to Wednesday to maximize the number of “uptime” days

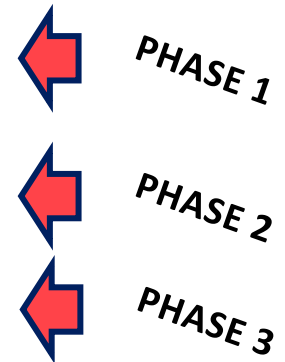
- Part of the setup during the week-end: really important to have lasing already on Friday

## IDEAL PROCEDURE

Document which describes the individual setup steps and actions to be taken for the different measurements results

## PROCEDURE IN PRACTICE

- Machine parameters **modified as little as possible** from the latest run before the shut-down
- Achieving lasing relatively **soon** is useful to setup the photon diagnostics also for further optimization
- Electron beam optimized **step by step**, looking at the lasing signal and the bandwidth as the best FEL detectors
- Bunch 2** using the setup of bunch 1 applying RF steps and the right timing. This defines the chronological order for the setup



# Electron beam performances

Measurements to **fully** characterize and optimize the e- beam:

- Emittance at the LH
- Bunch length and tilt at BC1
- Emittance at BC1 (slice and projected)
- Bunch length and tilt optimized at BC2
- Emittance at the energy collimator (slice and projected)
- Dispersion from the energy collimator

**Measured** and **reproduced** after some days the **design parameters** already from the first corona startup at the injector

Location	Measured (nm)	Design (nm)
LH (projected)	230	210
BC1 (slice)	140	145

Pulse length (rms)	Slice (nm)
44 fs (startup)	320
35 fs (startup)	300
25 fs (after more optimization)	320

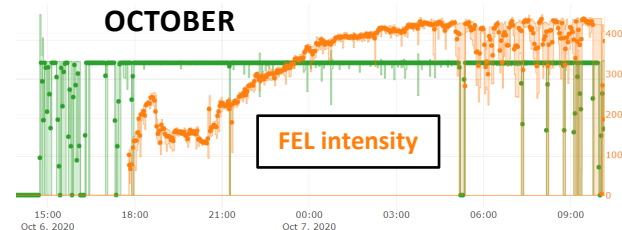
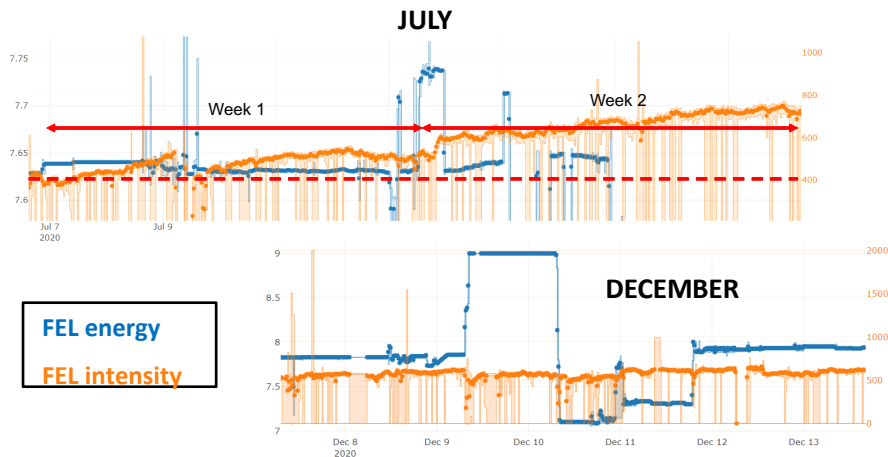
The emittance at the energy collimator depends on the compression setup and beam transport, and the time spent to optimize it (**manually** and using **PSICO**), but we typically measure around 300 nm slice emittance



# Aramis\* photon intensity performances

## Relatively quickly high lasing intensity achieved

- After day 1 (manually): 300 uJ at 11.3 keV
- One night of PSICO: 350-450 uJ
- Some more tweaking: > 400 uJ



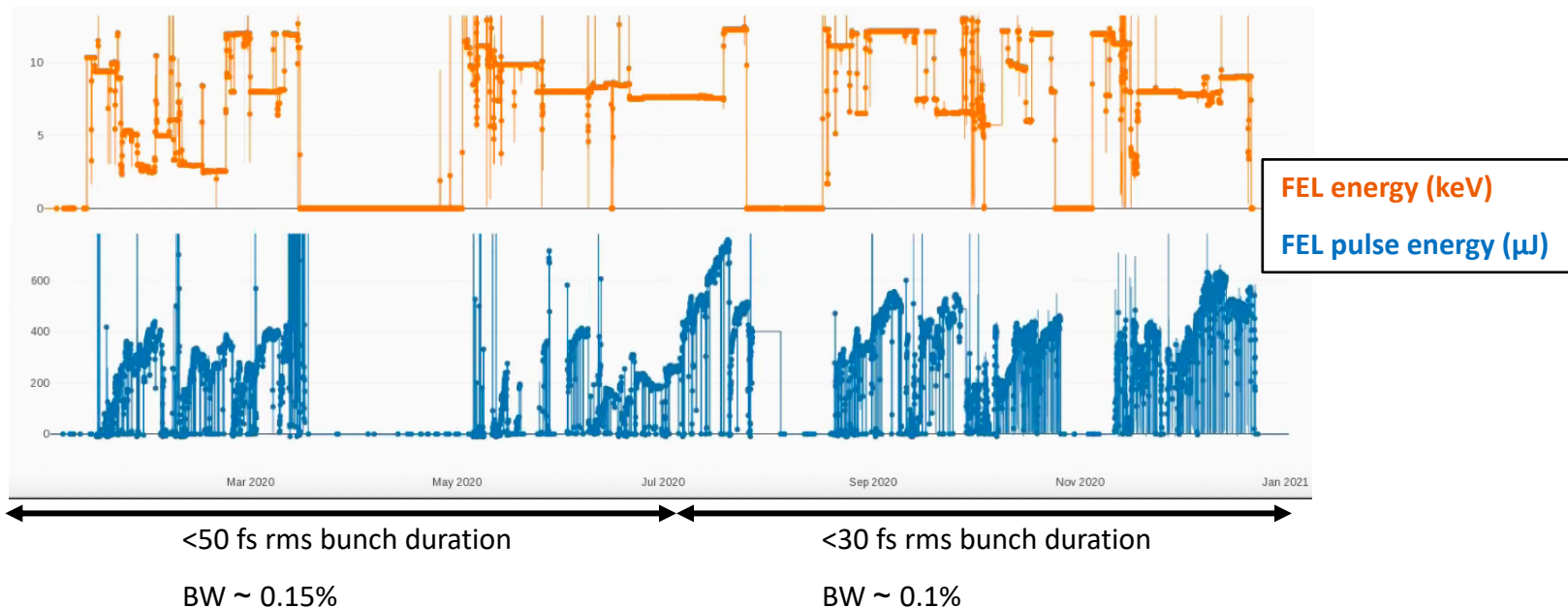
## FEL optimization improved during the year

- Minimal modification of the machine parameters from one week to the following
- High lasing intensity achieved and maintained

- Parameters required from the users always **achieved from day 1**
- Good **reproducibility** of the machine performances
- **Stable** beam or further optimized FEL intensity during the photon delivery weeks (PSICO and manual tweaking alternating)

## Aramis\* photon intensity 2020

Semi-remote operation (operation on-site)



Examples for achieved pulse energies at several photon energies

570  $\mu\text{J}$  @ 12 keV  
620  $\mu\text{J}$  @ 9 keV  
780  $\mu\text{J}$  @ 7.5 keV

but more important several weeks of **continuous** high FEL delivery

# Observed difficulties

→ Please also look at 2020 presentation, many things still apply

- **Reliability and consistency of machine setups**
  - Great performance could be reached both in Aramis and Athos (parallel)
    - Could not be reproduced easily in Athos
    - More work in Athos line recently improved the situation
  - Start-up: significant improvements with respect to 2019
- **High load on key personnel, only few experts**

## **Regulations / Safety / Machine Safety**

- Very important to make sure permits from our authorities are always respected
- Beam losses in the undulators are critical
  - Great improvement in Aramis after beginning of 2020
  - Athos still has potential, but this year started with a tremendous improvement

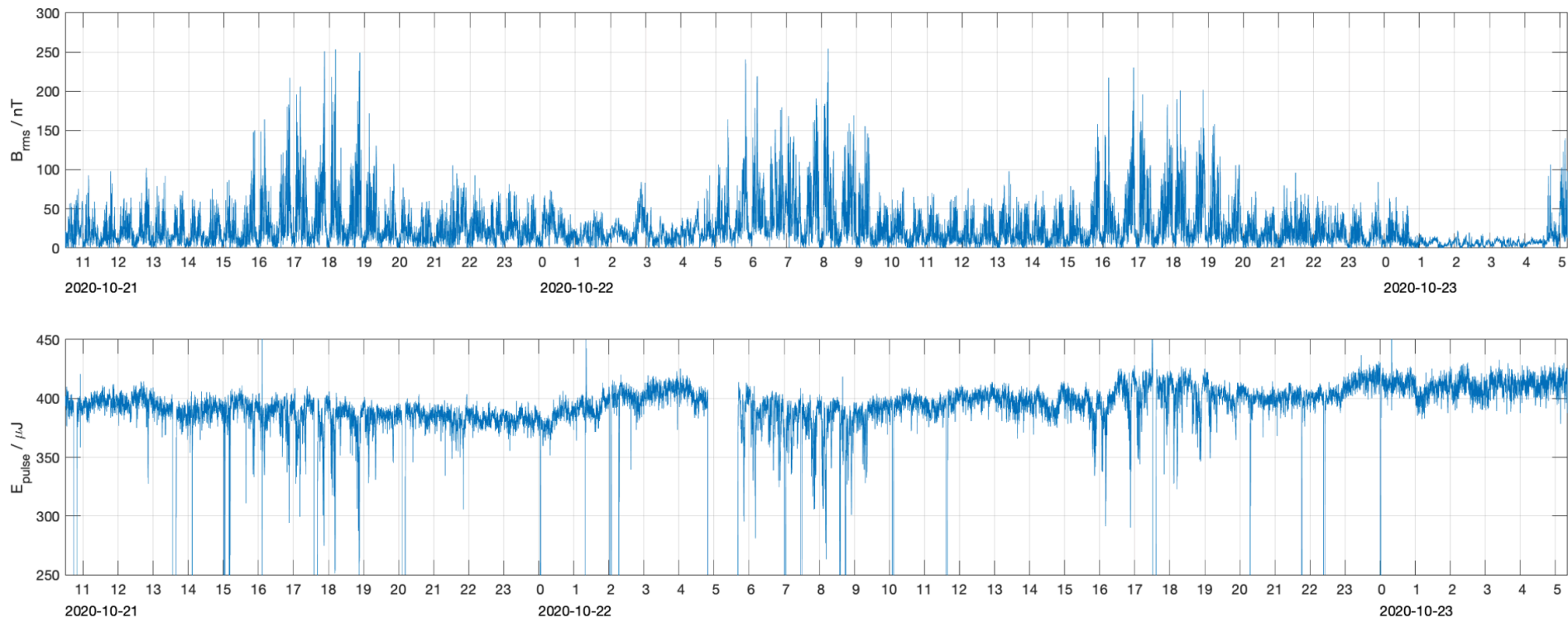
## **50 Hz distortions on beam parameters**

- AC PLL development under way, first step to improve / characterize situation
- Further developments may be required

## **Motor controllers in SwissFEL**

- Are end-switches now 'safe'? → To be clarified in 2021

Observed major performance degradation in SwissFEL, caused by trains.



## SwissFEL near Gun, Friday afternoon and Saturday morning





# Major objectives 2021

## Parallel operation of two beam lines

- Parallel operation has to become the norm
  - Performance has to become very good in **both beam lines at the same time!**
- Intelligent scheduling and very good communication are key
  - The two beam lines are very strongly coupled
  - Changes in the common machine path will affect both lines
    - Further work on de-coupling of lines required (but has limits)
  - Important to discuss all planned experiments internally within PSD and also with GFA to exclude competing requirements
  - Scheduling should make sure the number of required changes to the machine is minimum

**Athos commissioning and first successful experiments!**

## SwissFEL DUO calendar Q1/Q2 2021 - Athos

W	January	W	February	W	March	W	April	W	May	W	June
53	Fri 1	05	Mon 1	09	Mon 1	13	Thu 1	17	Sat 1	22	Tue 1
	Sat 2		Tue 2		Tue 2		Fri 2		Sun 2		Wed 2
	Sun 3		Wed 3		Wed 3		Sat 3	18	Mon 3		Thu 3
01	Mon 4		Thu 4		Thu 4		Sun 4		Tue 4		Fri 4
	Tue 5		Fri 5		Fri 5	14	Mon 5		Wed 5		Sat 5
	Wed 6		Sat 6		Sat 6		Tue 6		Thu 6		Sun 6
	Thu 7		Sun 7		Sun 7		Wed 7		Fri 7	23	Mon 7
	Fri 8	06	Mon 8	10	Mon 8		Thu 8		Sat 8		Tue 8
	Sat 9		Tue 9		Tue 9		Fri 9		Sun 9		Wed 9
	Sun 10		Wed 10		Wed 10		Sat 10	19	Mon 10		Thu 10
02	Mon 11		Thu 11		Thu 11		Sun 11		Tue 11		Fri 11
	Tue 12		Fri 12		Fri 12	15	Mon 12		Wed 12		Sat 12
	Wed 13		Sat 13		Sat 13		Tue 13		Thu 13		Sun 13
	Thu 14		Sun 14		Sun 14		Wed 14		Fri 14	24	Mon 14
	Fri 15	07	Mon 15	11	Mon 15		Thu 15		Sat 15		Tue 15
	Sat 16		Tue 16		Tue 16		Fri 16		Sun 16		Wed 16
	Sun 17		Wed 17		Wed 17		Sat 17	20	Mon 17		Thu 17
03	Mon 18		Thu 18		Thu 18		Sun 18		Tue 18		Fri 18
	Tue 19		Fri 19		Fri 19	16	Mon 19		Wed 19		Sat 19
	Wed 20		Sat 20		Sat 20		Tue 20		Thu 20		Sun 20
	Thu 21		Sun 21		Sun 21		Wed 21		Fri 21	25	Mon 21
	Fri 22	08	Mon 22	12	Mon 22		Thu 22		Sat 22		Tue 22
	Sat 23		Tue 23		Tue 23		Fri 23		Sun 23		Wed 23
	Sun 24		Wed 24		Wed 24		Sat 24	21	Mon 24		Thu 24
04	Mon 25		Thu 25		Thu 25		Sun 25		Tue 25		Fri 25
	Tue 26		Fri 26		Fri 26	17	Mon 26		Wed 26		Sat 26
	Wed 27		Sat 27		Sat 27		Tue 27		Thu 27		Sun 27
	Thu 28		Sun 28		Sun 28		Wed 28		Fri 28	26	Mon 28
	Fri 29			13	Mon 29		Thu 29		Sat 29		Tue 29
	Sat 30				Tue 30		Fri 30		Sun 30		Wed 30
	Sun 31				Wed 31			22	Mon 31		

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	Sat 2		Tue 2		Tue 2		Fri 2		Sun 2		Wed 2
	Sun 3		Wed 3		Wed 3		Sat 3	18	Mon 3		Thu 3
01	Mon 4		Thu 4		Thu 4		Sun 4		Tue 4		Fri 4
	Tue 5		Fri 5		Fri 5	14	Mon 5		Wed 5		Sat 5
	Wed 6		Sat 6		Sat 6		Tue 6		Thu 6		Sun 6
	Thu 7		Sun 7		Sun 7		Wed 7		Fri 7	23	Mon 7
	Fri 8		Mon 8	10	Mon 8		Thu 8		Sat 8		Tue 8
	Sat 9	06	Tue 9		Tue 9		Fri 9		Sun 9		Wed 9
	Sun 10		Wed 10		Wed 10		Sat 10	19	Mon 10		Thu 10
02	Mon 11		Thu 11		Thu 11		Sun 11		Tue 11		Fri 11
	Tue 12		Fri 12		Fri 12	15	Mon 12		Wed 12		Sat 12
	Wed 13		Sat 13		Sat 13		Tue 13		Thu 13		Sun 13
	Thu 14		Sun 14		Sun 14		Wed 14		Fri 14	24	Mon 14
	Fri 15	07	Mon 15	11	Mon 15		Thu 15		Sat 15		Tue 15
	Sat 16		Tue 16		Tue 16		Fri 16		Sun 16		Wed 16
	Sun 17		Wed 17		Wed 17		Sat 17	20	Mon 17		Thu 17
03	Mon 18		Thu 18		Thu 18		Sun 18		Tue 18		Fri 18
	Tue 19		Fri 19		Fri 19	16	Mon 19		Wed 19		Sat 19
	Wed 20		Sat 20		Sat 20		Tue 20		Thu 20		Sun 20
	Thu 21		Sun 21		Sun 21		Wed 21		Fri 21	25	Mon 21
	Fri 22	08	Mon 22	12	Mon 22		Thu 22		Sat 22		Tue 22
	Sat 23		Tue 23		Tue 23		Fri 23		Sun 23		Wed 23
	Sun 24		Wed 24		Wed 24		Sat 24	21	Mon 24		Thu 24
04	Mon 25		Thu 25		Thu 25		Sun 25		Tue 25		Fri 25
	Tue 26		Fri 26		Fri 26	17	Mon 26		Wed 26		Sat 26
	Wed 27		Sat 27		Sat 27		Tue 27		Thu 27		Sun 27
	Thu 28		Sun 28		Sun 28		Wed 28		Fri 28	26	Mon 28
	Fri 29			13	Mon 29		Thu 29		Sat 29		Tue 29
	Sat 30				Tue 30		Fri 30		Sun 30		Wed 30
	Sun 31				Wed 31			22	Mon 31		

# Major objectives 2021

## **Deliver and maintain peak performance**

- Further enhance reproducibility of setup procedures, tools, and automation
- Better management of (major) changes to machine settings
- Improved organization of machine study periods, important aspects include:
  - Commissioning
  - New developments
  - But also:
    - Improvements of daily machine performance
    - Fast and complete 'recovery' from machine study blocks
    - Training and automation

## **Long-term goal: increase available user time in Aramis and Athos**

- Reduction of shutdown durations
- Reduction of number of maintenance windows

## Porthos

- New working groups established in Summer 2020 to work out proposal for third FEL beam line
- Working groups led by T. Schietinger (machine) and M. Stampanoni (photonics)

Comment:

Design should take into account already now the fourth beam line D'Artagnan (e.g. for bunch distribution scheme, etc.)



# ‘One SwissFEL’ – final remark

All for one, one for all!



# Acknowledgments

Thanks to...

- All involved groups for their contributions to the workshop and for making SwissFEL a success!

