Facility Report – DESY –

ARD-ST3 Annual Meeting 2023

Covering today:

- PETRA III / IV
- FLASH / FLASH2020+
- EuXFEL / Upgrade

Not covered

- PITZ / ARES / REGAE / diverse test stands

Holger Schlarb, Group Leader MSK/DESY

HZDR, Dresden, 05. July 2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

DESY activities : birds view …

European XFEL +

X-Ray Free-Electron Laser
atomic structure & fs dynamics of complex matter

PETRA III

Synchrotron Radiation of Highest Brightness
atomic structure of complex matter

FLASH

VUV & Soft X-ray Free-Electron Laser
fs dynamics of complex matter (spectroscopy)

PETRA III / PETRA IV

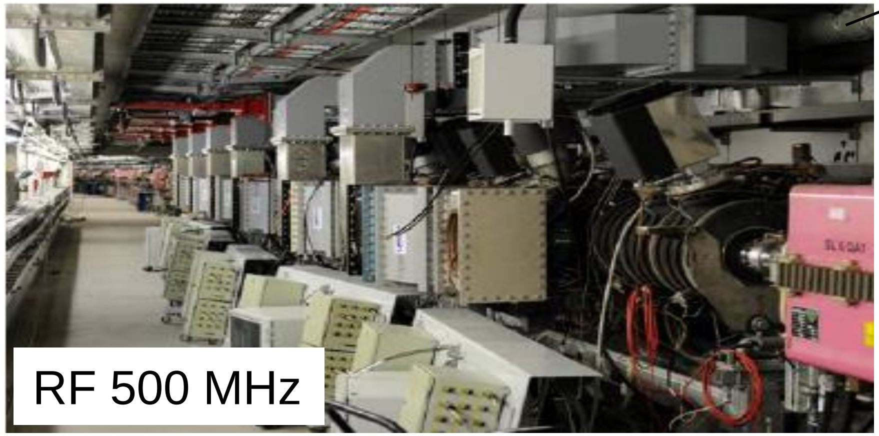
PETRA III

Courtesy: R. Wanzenberg

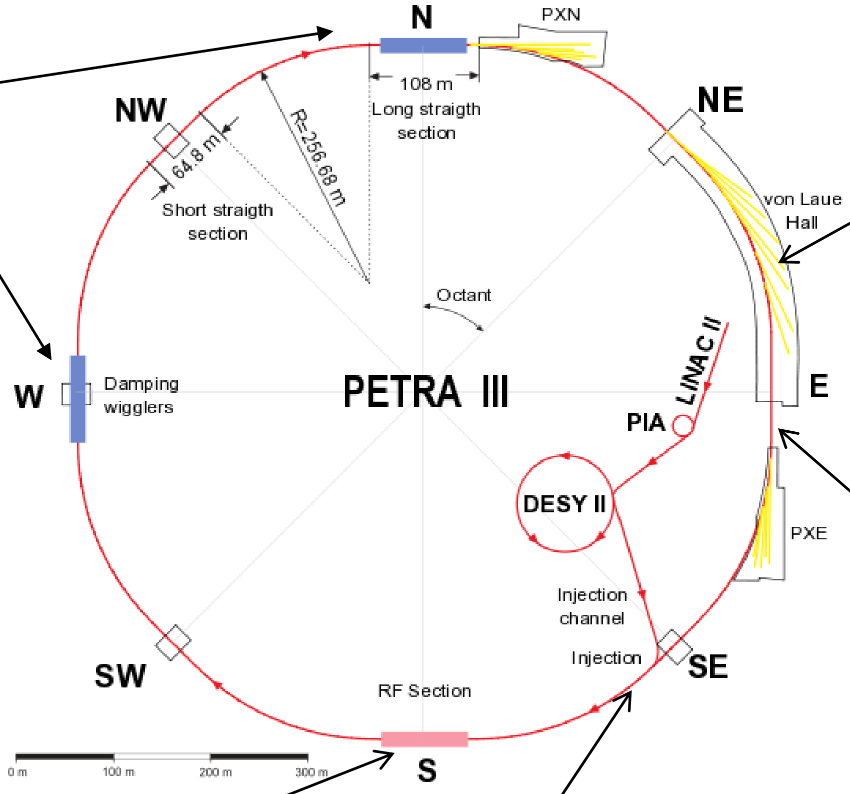
Wigglers 80m

ε_x: 5 nm → 1.2 nm

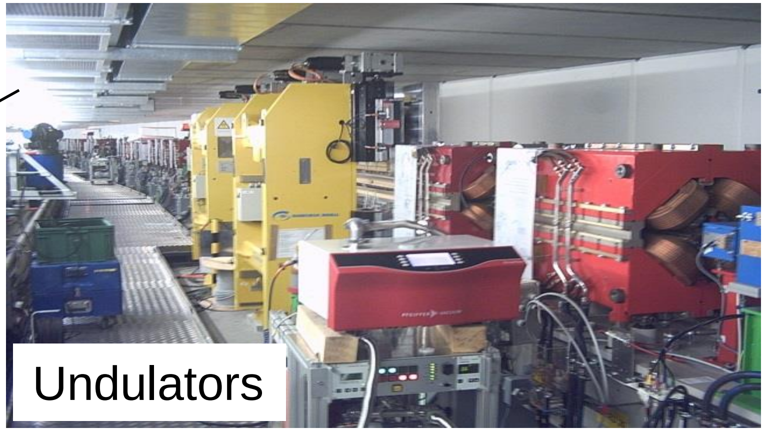
FODO Arc



RF 500 MHz



Injection



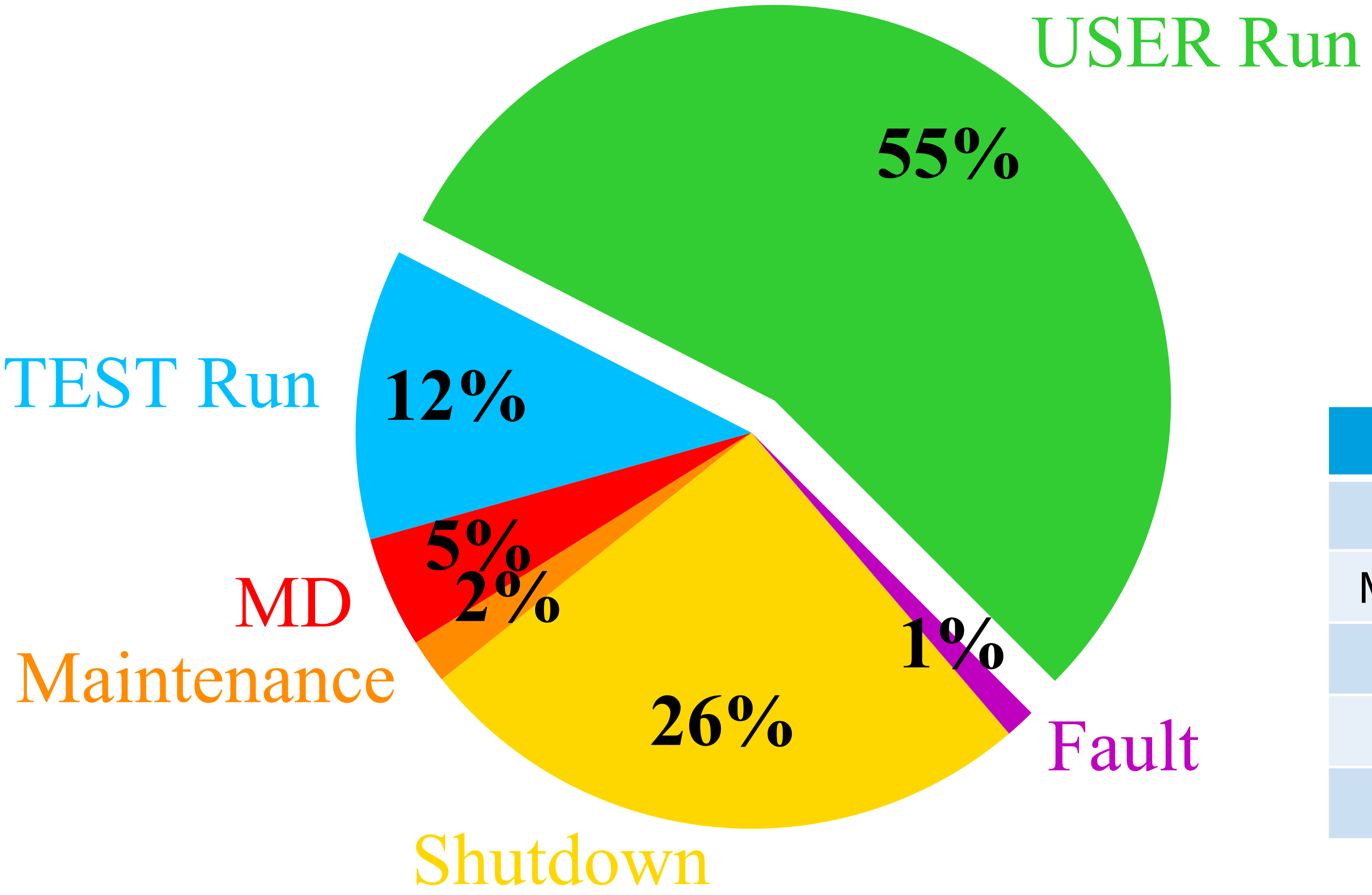
Undulators

Long. MBFB Feedback

Parameter	PETRA III	
Energy / GeV	6	
Circumference /m	2304	
Emittance (horz. / vert.) /nm	1.2 / 0.012	
Total current / mA	100	
Number of bunches	960	40
Bunch population / 10^{10}	0.5	12
Bunch separation / ns	8	192

4815 h of User Time Delivered 16.2. – 19.12.2022

Full Statistics for 01.01 – 31.12.2022



Availability **98.3 %**
MTBF: **58 h**
MTTR: **1 h**

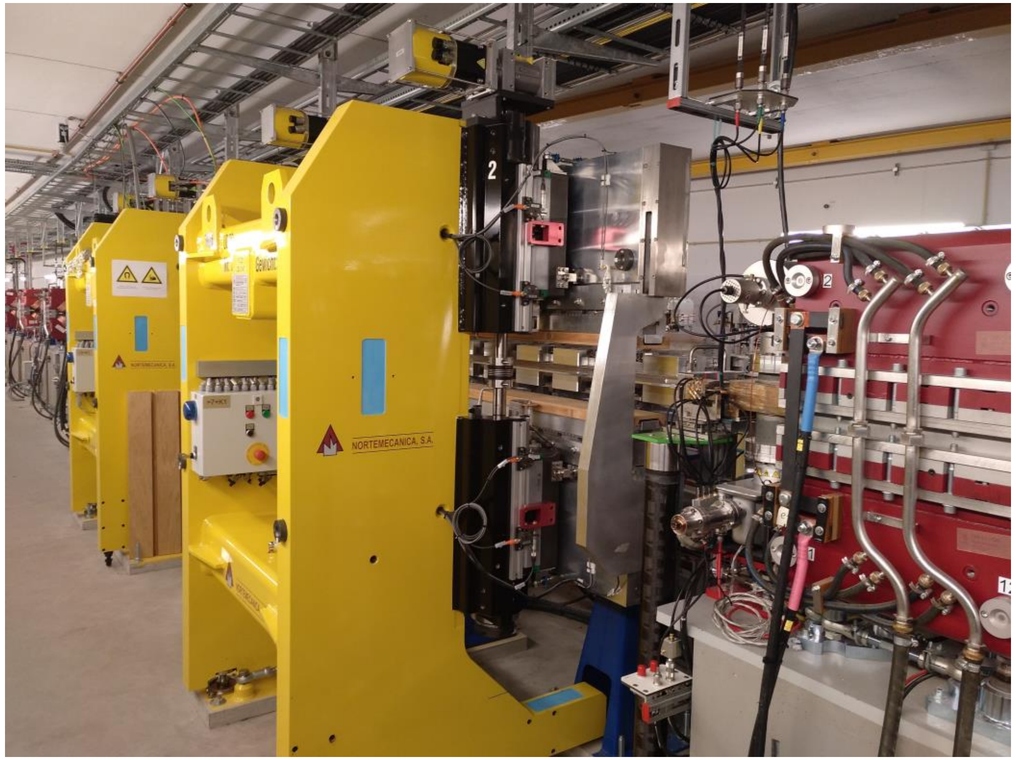
USER Run	4815 h
Test Run	1041 h
Machine Development (MD)	398 h
Maintenance	158 h
Shutdown	2240 h
Fault	108 h

Courtesy: M. Schaumann

Last Undulator in PXE Installed: Beamline P25

Connection to control system and commissioning during summer shutdown 2023

- Last undulator spot in PXE hall has been filled to provide photons to beamline P25 (canted cell with P24)
- One last open spot at PU63 remains in PXN hall



Courtesy: M. Schaumann

PETRA VI Prototype Cavity sees PETRA III Electron Beam

Currently in detuned operation – solid state amplifier expected in summer

Prototype 500MHz HOM-damped cavity installed during winter shutdown.

- Good damping of higher order modes > 615 MHz
- Similar designs are used at e.g. ALBA, BESSY, DIAMOND, ERSR, SLS, ALS

- Since February in detuned operation with beam
- Tests at operational currents and beam patterns show expected (inconspicuous) behavior.

R. Onken

PETRA IV. NEW DIMENSIONS

Cavity installed Jan 2023

Courtesy: M. Schaumann

12 BPM Signals Split for Study of new Readout Electronics

Parallel operation with existing Libera Brilliance system

PETRA IV. NEW DIMENSIONS

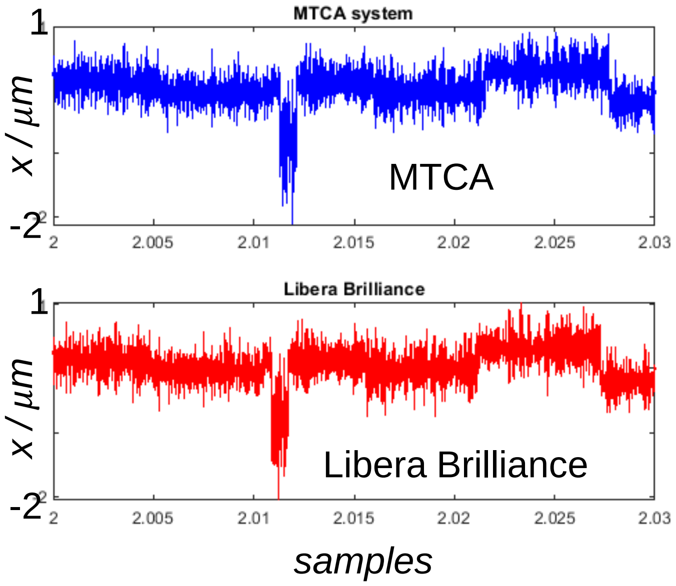
INSTRUMENTATION TECHNOLOGIES

Prototype MTCA-based system installed at PETRA III

Gero Kube

Status:

- Integration in PETRA III environment
- Basic data exchange and control scrips
- First functional tests and data taking



Comparison MTCA and Libera Brilliance:

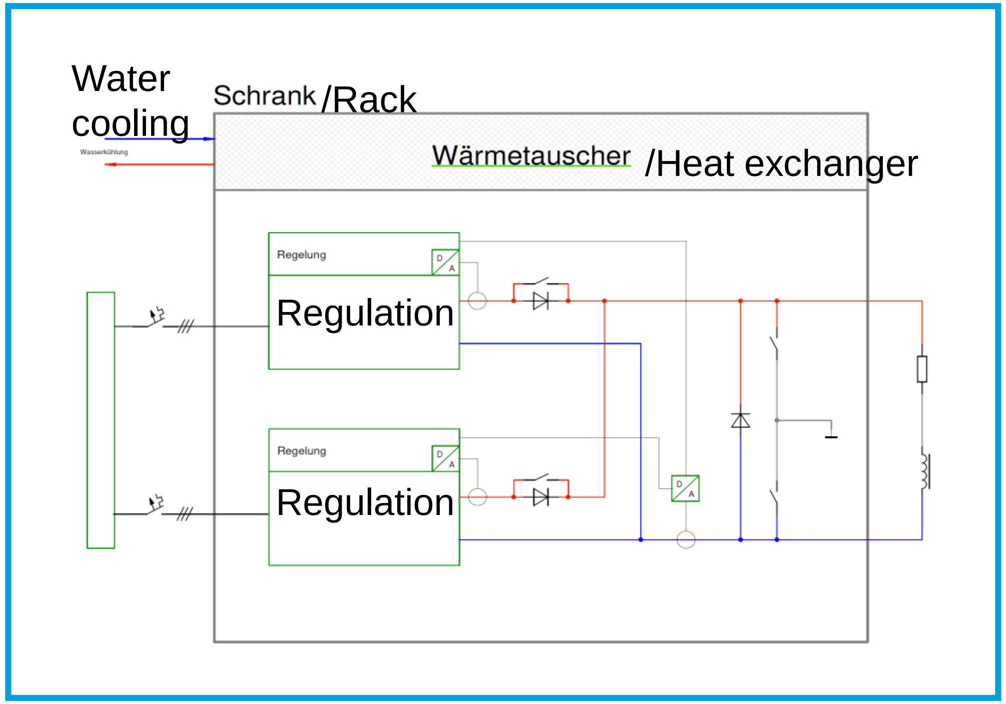
→ both electronics see same signal

Courtesy: M. Schaumann

Hot Swap Redundancy Concept is being tested in PETRA III

First tests with high beam current were successful

Hot-Swap system V3.0



Large amount of power supplies (PS) in PETRA IV requires **Hot-Swap concept**:

→ Two independent PS per magnet

→ Fast detection of failure by monitoring output filter current

→ Second PS takes over in case of failure

First tests with beam in PETRA III show good results:

- No signs of disturbance in lifetime, orbit feedback currents or orbit
- Tested hot-swap on quadrupole in Max von Laue Hall
- Turn-by-turn data measured with one BPM
- Further tests are in progress

PETRA IV. NEW DIMENSIONS

H.-J. Eckoldt
C. Putscher

Courtesy: M. Schaumann

PETRA IV Civil Engineering during PETRA III Operation

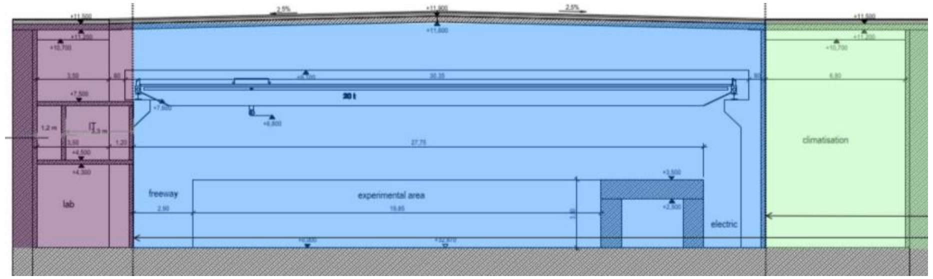
Impact on beam operation is under study

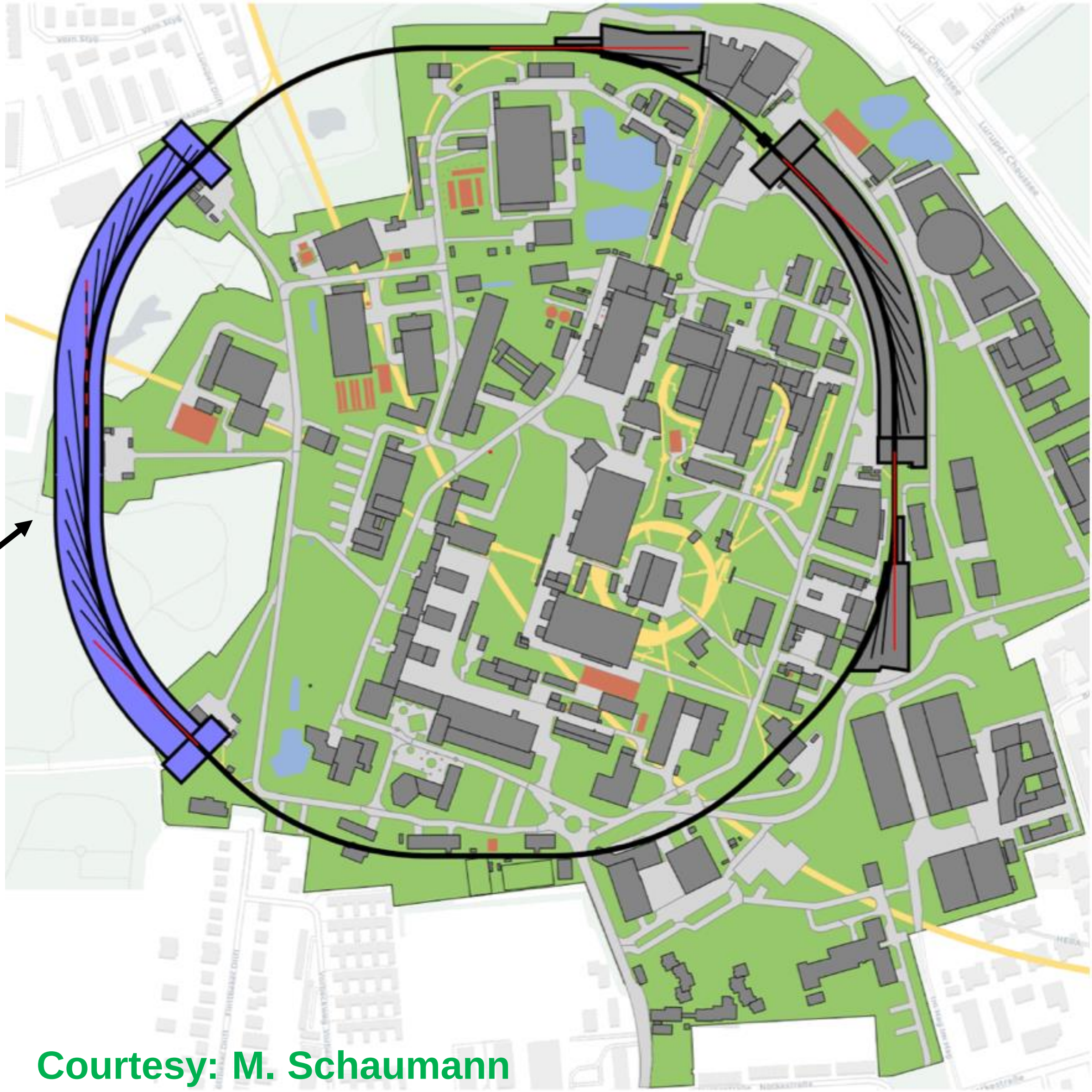
Construction of new experimental hall needs to start before PETRA IV shutdown

Excavation work should start **during PETRA III operation**
→ Vibrations are expected
→ Need to ensure photon beam quality and availability

Estimates of impact on PETRA III beam required

Cross-section of future experimental hall that needs to be excavated





Courtesy: M. Schaumann

PETRA IV.
NEW DIMENSIONS

Project Status: TDR phase

Dedicated Adv. Com: TAC = Technical Advisory Committee for PETRA IV

PIV Project Management

Riccardo Bartolini
Machine Project Leader

Harald Reichert
Project Leader

CDR

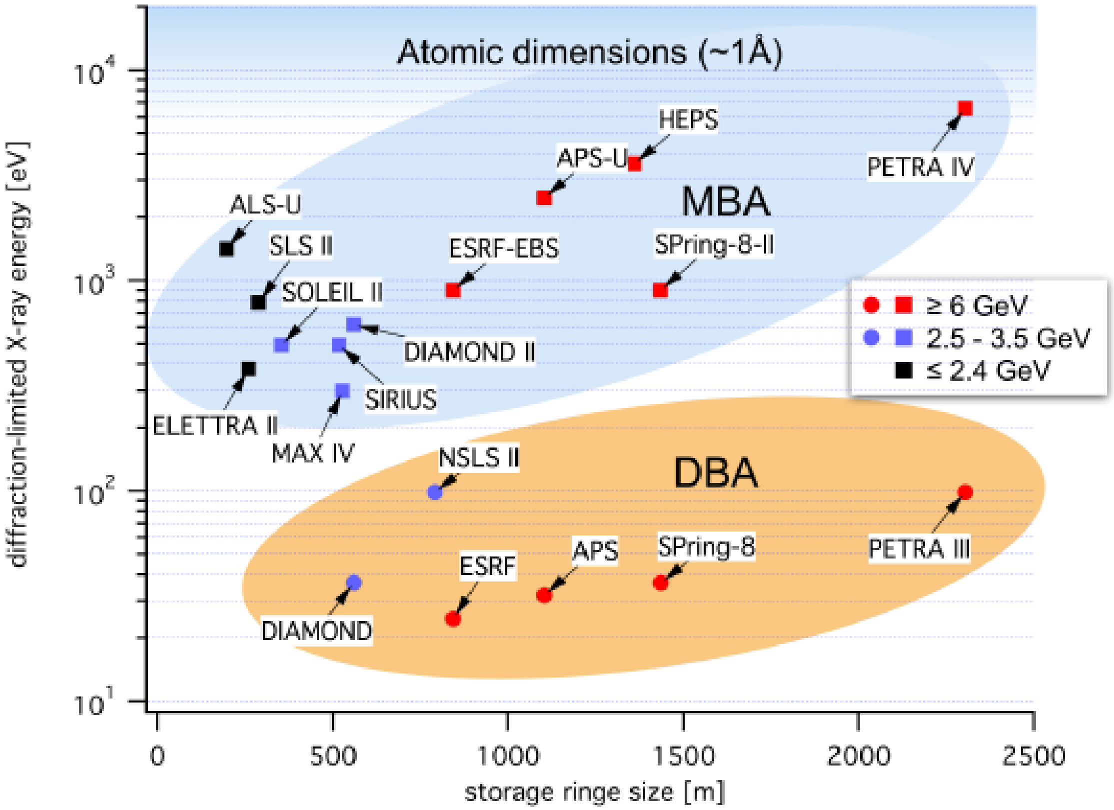
DOI: 10.3204/PUBDB-2019-03613

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

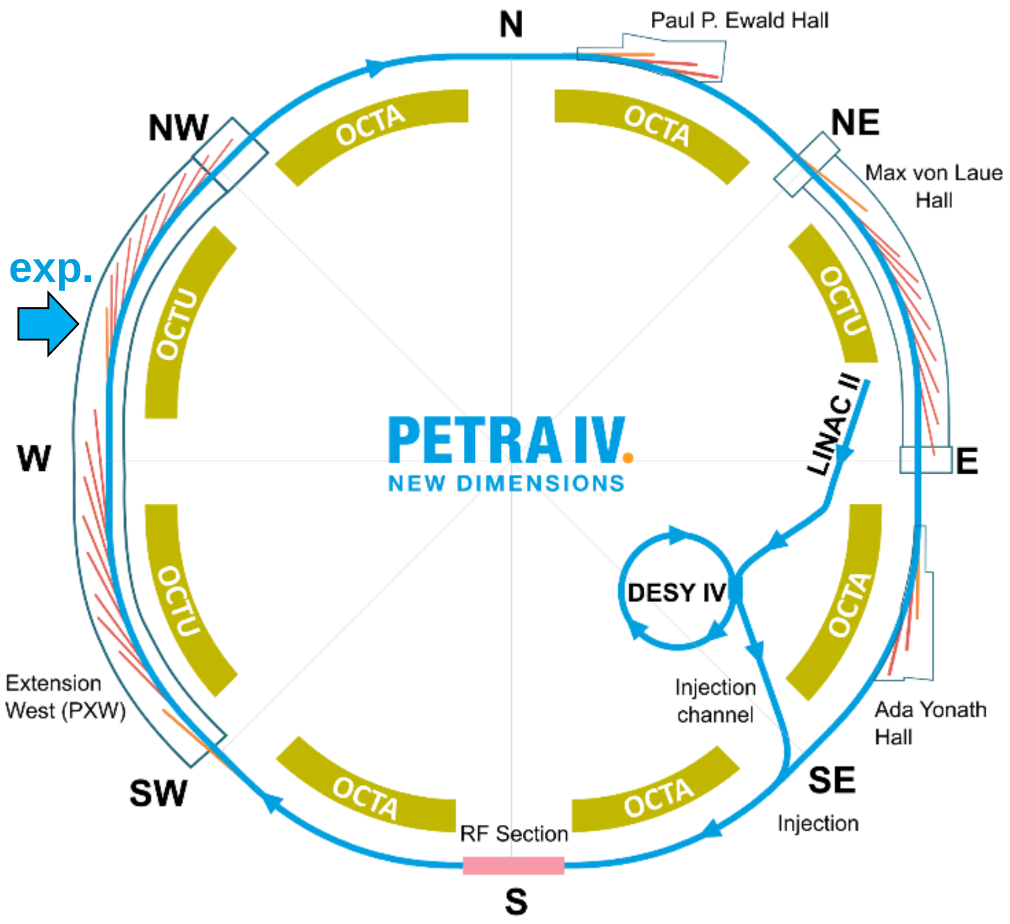
DESY.

PETRA IV

- Diffraction-limited photon energy for synchrotron radiation sources and there upgrades
- Pressure for DESY to upgrade PIII → PIV to stay competitive in the world!



Change of lattice H6BA outperforms the combi lattice



New exp. hall

- **Brightness mode**: 200mA, 4ns spacing (2)
  (~1600-1920 bunches with or w/o gaps)
- **Timing mode**: 96 ns spacing (80 bunches) (40)

H7BA

	H6BA	Combi
Tunes ν_x, ν_y	135.18, 86.27	154.18, 66.27
Natural chrom. ξ_x, ξ_y	-233, -156	-200,-170
Mom. comp. α_C	3.3 10^{-5}	1.8 10^{-5}
U_0	4.17 MeV	3.9 MeV
Standard ID section	4.7 m - 4.9 m	5.3 m
Hor. Emittance w/o IDs, zero current	20 pm	18 pm
Hor. Emittance with IDs, zero current	20 pm	9.2 pm
Rel. energy spread with IDs, zero current	0.9 10^{-3}	0.95 10^{-3}
Beta at ID	$\beta_x = 2.2\,m$ $\beta_x = 2.2\,m$	$\beta_x = 3.6\,m$ $\beta_x = 2.1\,m$
RF Voltage 1st / 3rd	8 MV, 2.4 MV	8 MV, 2.3 MV

➔ **Ver. Emittance** **4 pm** **4pm**

- Based on H6BA cell – 8 octants with 9 cells each
- Straight section for 5 flagship IDs

Courtesy: R. Bartolini

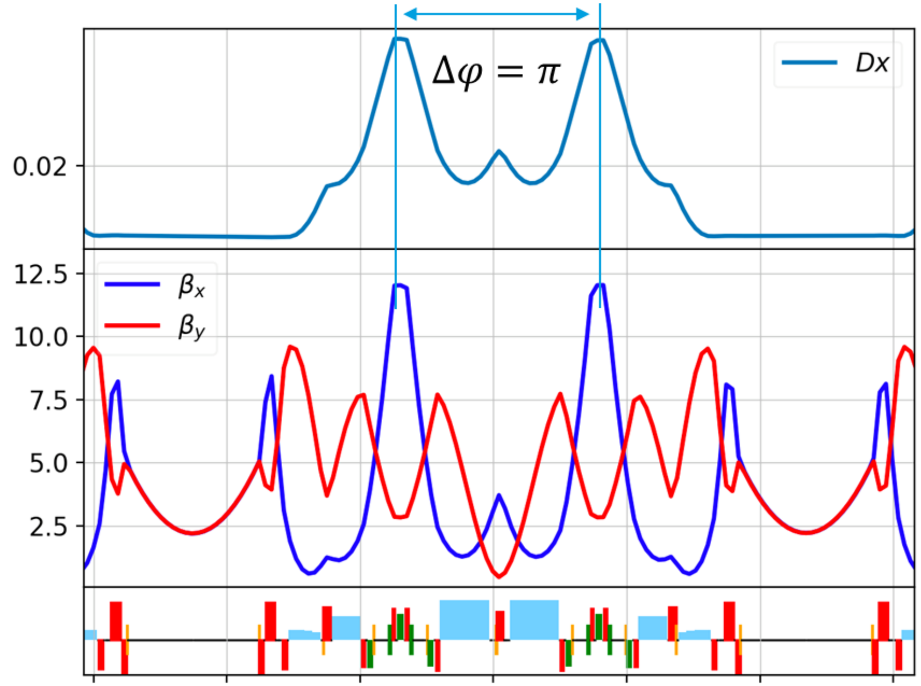
Changes from the CDR

- **Proposed H6BA lattice**
  - Significantly different from the one proposed for the CDR (scaling of ESRF-EBS H7BA)
  - New lattice combines HMBA + Damping Wigglers to reduce emittance
  - significantly improved apertures for injection and beam lifetime
  - The larger dynamic aperture allows off-axis accumulation,
  - Larger momentum aperture increases the Touschek lifetime
- **New design features** a better matching of the optics functions in the straight section
- **Permanent magnet combined function dipoles** ➔ reduced power consumption
- New design offers of **keeping the nine-cell structure in the octants**
  - limiting the movement of the existing source points
  - impact on the shielding geometry is significantly reduced
  - logistics and installation process are simplified
- **Downselection of the booster lattice** ➔ small emittance & relaxed charge requirements
- **Injection energy kept at 450 MeV**
  - reusing the refurbished LINAC II and the PIA accumulator ring

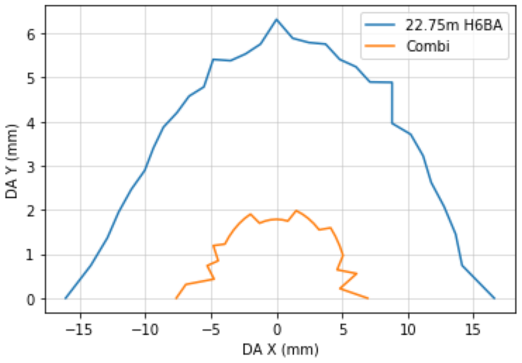
PETRA IV H6BA lattice

New lattice design → 43 pm (large emittance, due to > D_x)

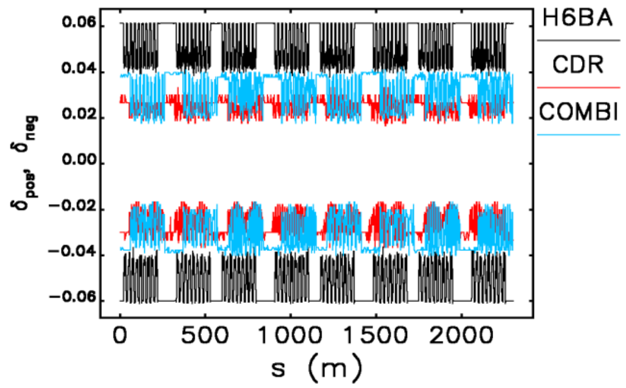
+ 40 damping wigglers → recover 20 pm emittance goals



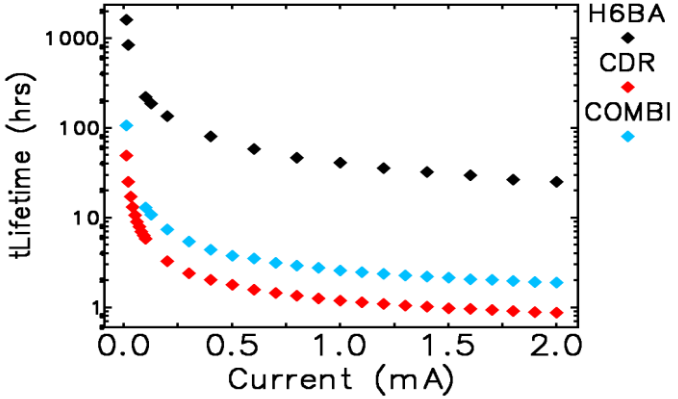
Dynamic aperture



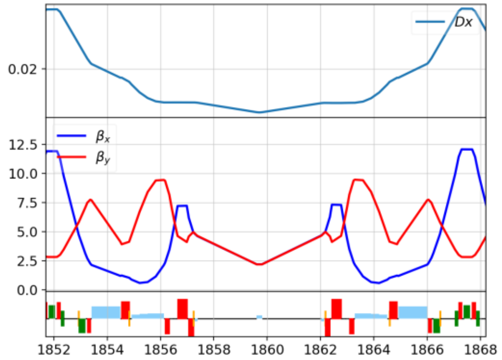
Local Momentum Accep.



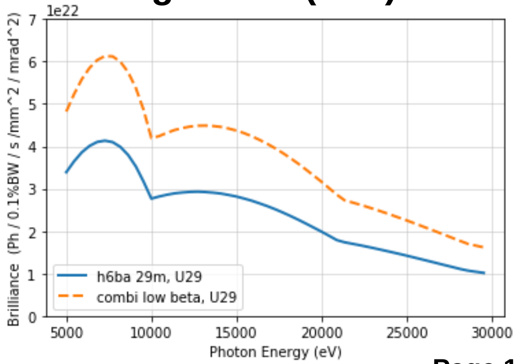
Lifetime



Canting possible



Brightness (U29)

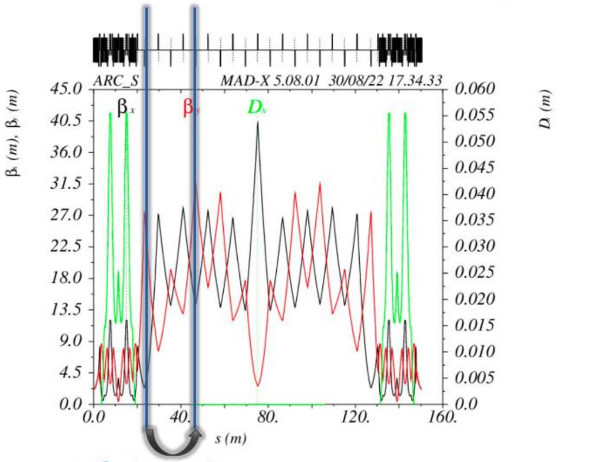


- ➢ Ease significantly injection chain ➔ off-axis injection (low charge operation)
- ➢ Preserves most of undulator beamline Max v. Laue Halle
- ➢ Relaxes somewhat tolerance & allow for easier canting & increases lifetime

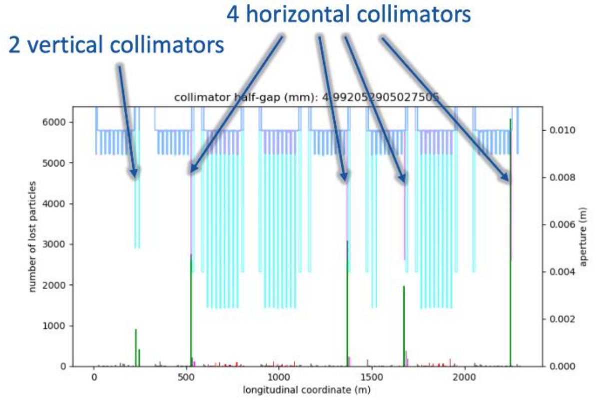
Courtesy: I. Agapov

Collimation design is improving

- Beam losses analysed in two modes: Touschek and RF off (with various levels of optics errors)



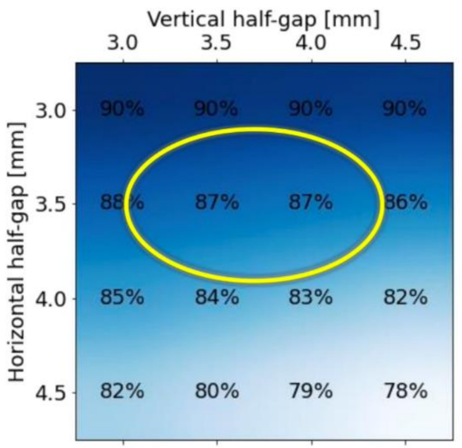
2 vertical collimators added in the South



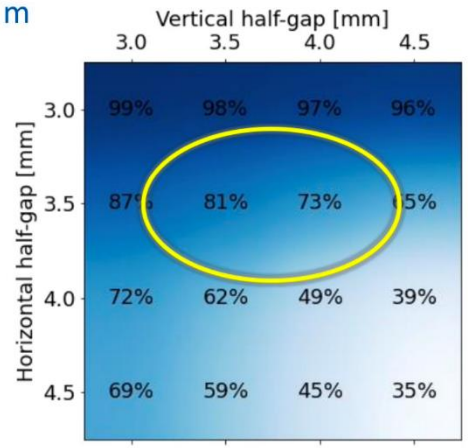
Refined aperture model:
2.5 mm in most of IDs

- Aperture model refined; engineering design ongoing
- Testing alternative location of the H collimator closed to the dispersion bump
- Improvement in collimation at the cost of slightly degraded DA
- Capture of >80% in both Touschek and RF off scenarios

at $\beta_y \approx 30$ m

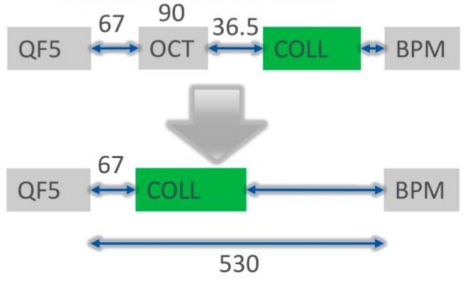


Touschek



RF off

- Removed 4 octupoles and rescaled the rest



Courtesy: R. Bartolini

c/o L. Malina, C. Cortes

FOFB system identification

Interfaces with other WPs

Core elements

- Power supply
- Cable
- BPM
- Magnet
- Vacuum Chamber
- Controller
- Delays (processing, communication, signal routing, …)

$$G(s) = \frac{Y(s)}{U(s)},$$

$Y(s)$ as output, $U(s)$ as input

s is the Laplace operator

WP 2.01:
Accelerator Physics

PETRA IV. NEW DIMENSIONS

WP 2.11:
Magnet Power Supplies

Current, Voltage
Update frequency
(>26kHz - simulated)
Resolution/Precision

Length, diameter, …
Insulation Material
(C', L', R')

WP 2.02:
Magnets

Magnetic field
Magnetic length
Inductance L

WP 2.04:
Vacuum Systems

Material
Dimensions
Inner coating

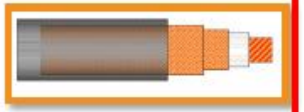
WP 2.05:
Diagnostics

Processing mode
(delay, noise)
Data rate

update

Power Supply

Cable



Magnet

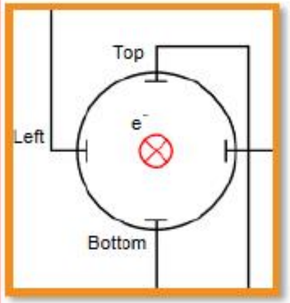
Figure 1: Prototype 8-Pole Corrector Magnet.

@APS

Vacuum Chamber

@LHC

BPM



→ Talk J.-M. Christmann

Controller

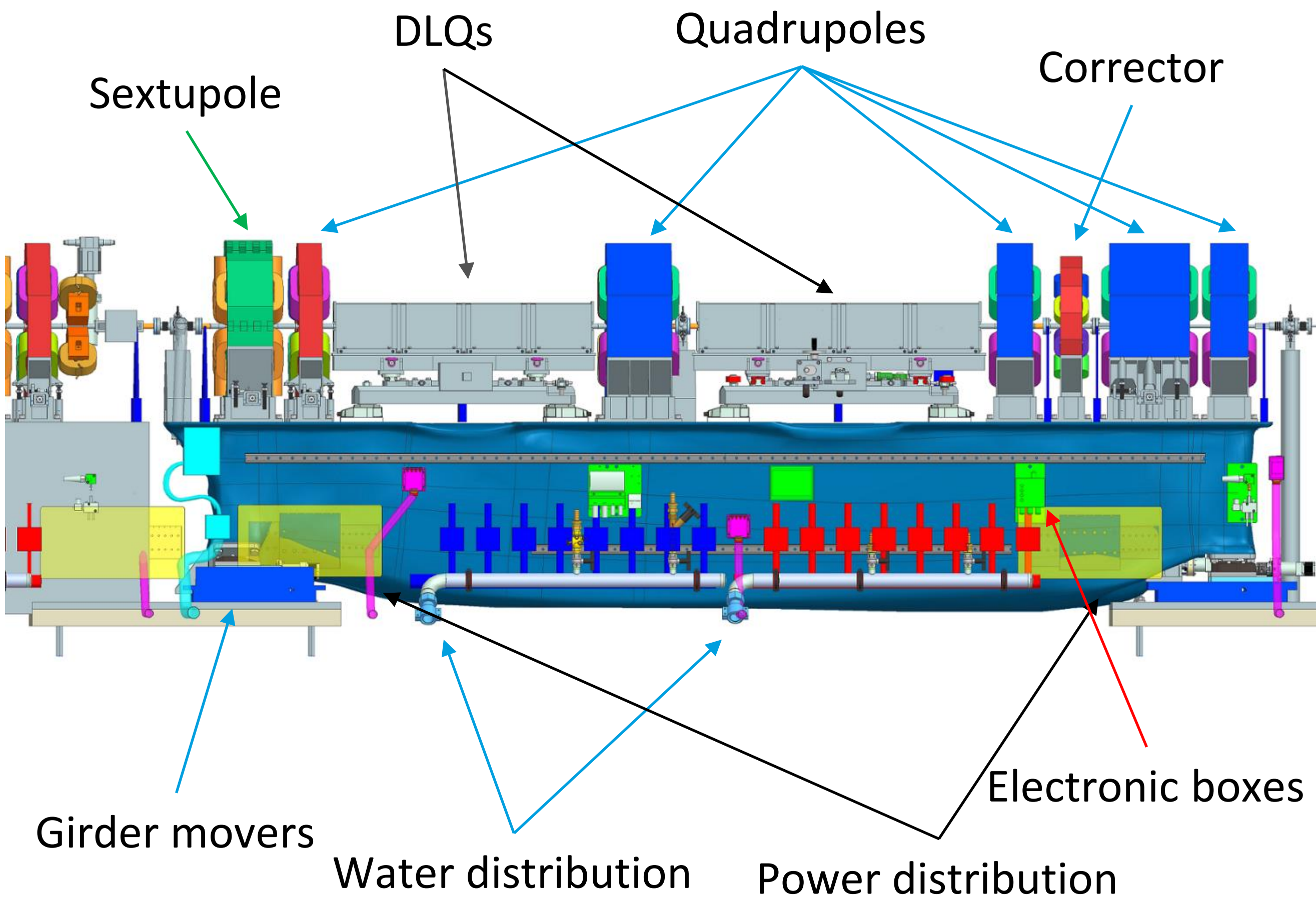
WP 2.08:
Feedbacks

Courtesy: S. Mirza

Prototype of a mock up girder is underway

A detailed list of scope and sequences of tests is being collected

Number	Task	Goal	responsible WP 2.xx	Duration
1	Measure EF's of the bare Girder	Same EF'S as simulation	06	1 day
2	Measure transfer functions G2G	gain information for feedback	06	2 days
3	Measure deflection of bare vs equipped Girder	Same EF'S as simulation	06	1+1 day
4	Measure EF's of the equipped Girder	Same EF'S as simulation	06	4 days
5	Measure EF's of the Magnets on the equipped Girder	gain information for feedback	06	5 days
6	Measure vibrations generated on the Girder	gain information	06	
7	Mover Tests	see if the girder can be moved	06,xx	7 days
8	Magnet placement/coarse alignment	be able to align +-0,2mm	06,07	5 days
9	Magnet fine alignment		07,06	
10	Girder Transport test, fine aligned		07,06	
11	Girder Transport test, equipped coarse aligned	see if magnets fall off	07,06	
12	test gluing procedure	check time needed	07,06	12 days
13	Assembly test vacuum system supports	Initial verification of assembly concept	04	
14	Assembly test vacuum string	Verify GAB-like installation of full string	04	
15	Assembly test for activation configuration	Verify that activation can be done	04	
16	Tests on cable routing and cooling for vacuum system	Ensure access to all relevant components during operation. Ensure Maintainability.	04	



and may more …

Courtesy: R. Bartolini

PETRA IV – Infrastructure

Civil construction programme

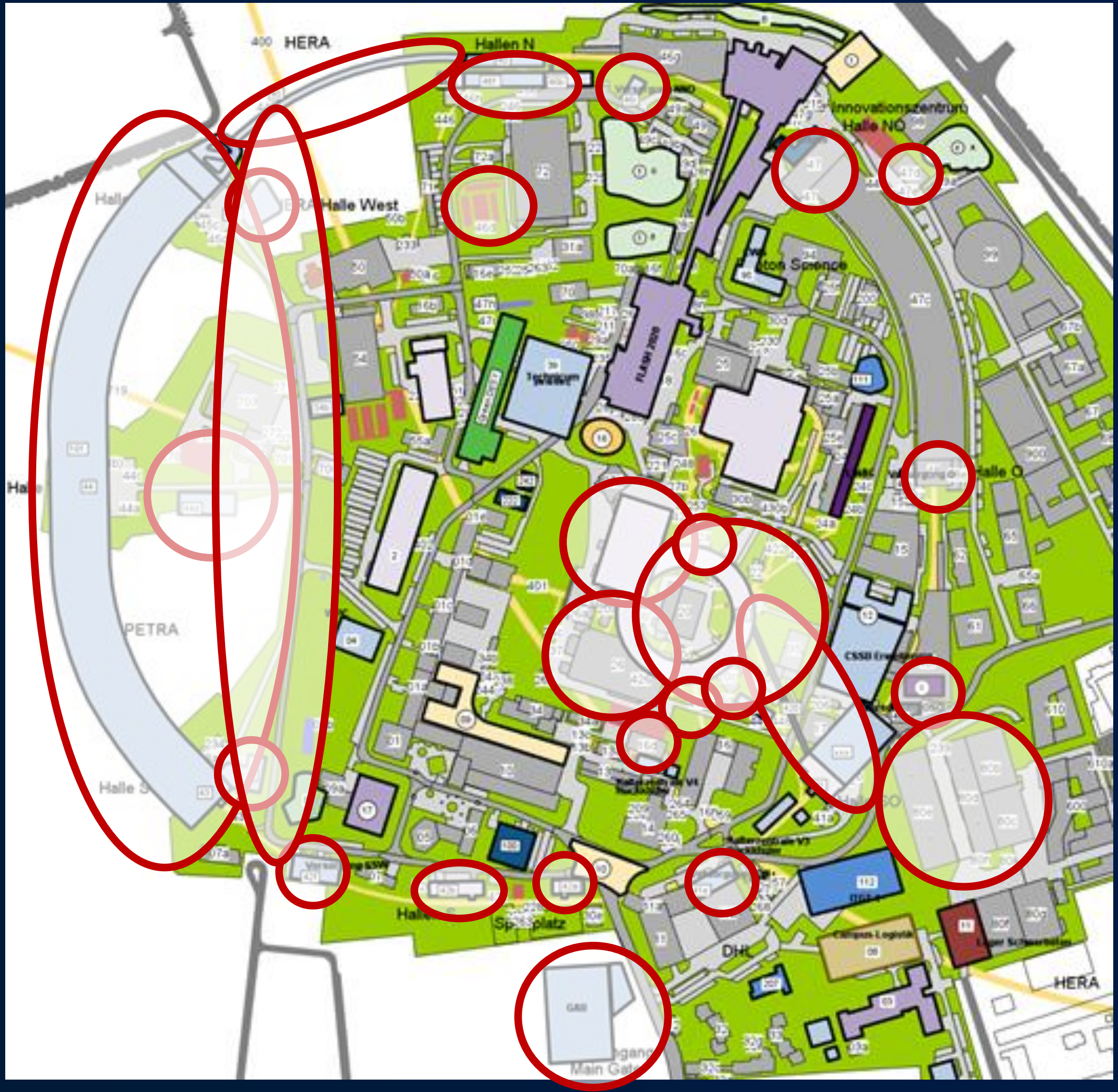
Buildings: Construction & Refurbishment Programme

Preparation phase:
Girder-Assembly Building(GAB), Reemtsma Halls

- Storage of PETRA IV components
- Preparation of components for assembly
- Assembly of the PETRA IV girders
- Storage of PETRA III components

Main project phase: Building infrastructure

- Tunnel refurbishment
- Construction of access and supply buildings
- RF Hall
- Infrastructure for pre-accelerators (DESY IV, TL)
- Experimental Hall West (PXW) + supply buildings



The *PETRA IV project* timeline is still challenging

PETRA IV. NEW DIMENSIONS

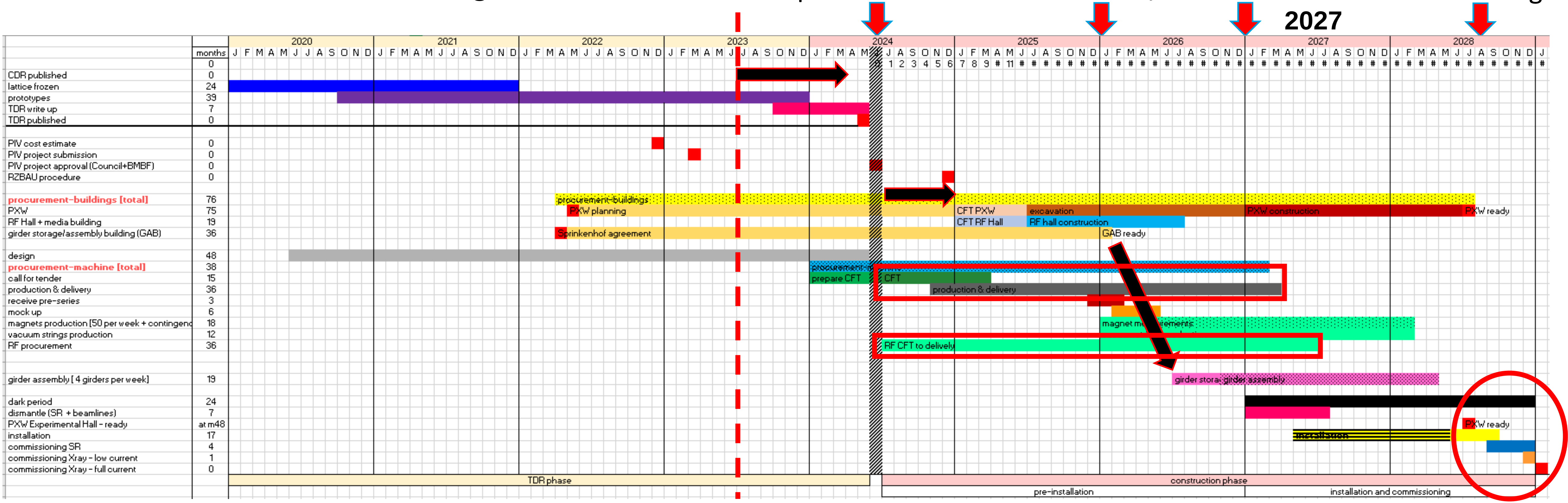
TDR extended with bridging fund from DESY
(5M per year in 2023 - 2024)
Procurement estimated to 3 years
GAB occupation by Jan 2026
PXW occupation by August 2028
Installation completed October 2028
Three months commissioning time

The draft breakdown below hinges on

- Project approval in mid 2024
- Call for tender start in mid 2024
- **Dark period 24 months**
- **First light in Jan 2029**

the project is built on the basis of these 2 constraints

start procurement | start assembly | PIII shut down | 2027 | PIV ring commissioning



FLASH

&

FLASH2020+

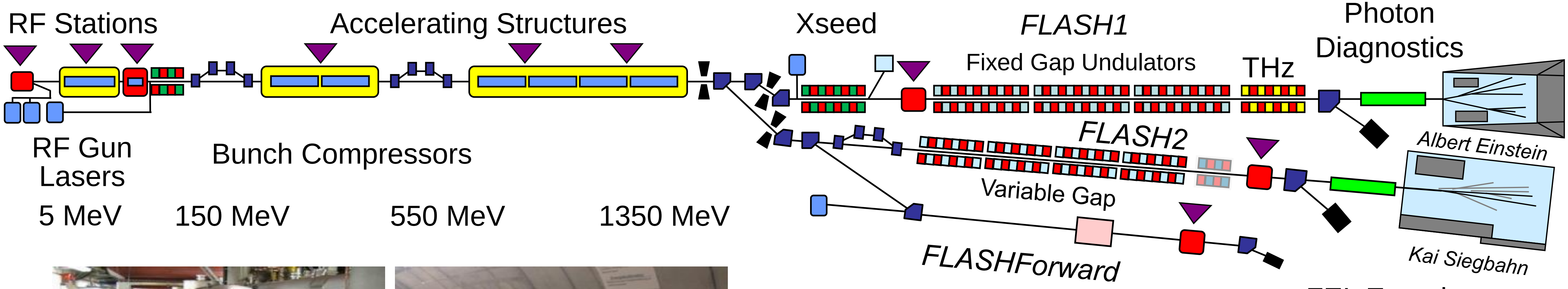
FLASH Layout – after the shutdown

3rd harmonic sc module 3.9 GHz

TESLA type superconducting accelerating modules 1.3 GHz

FLASH1 fixed gap undulators

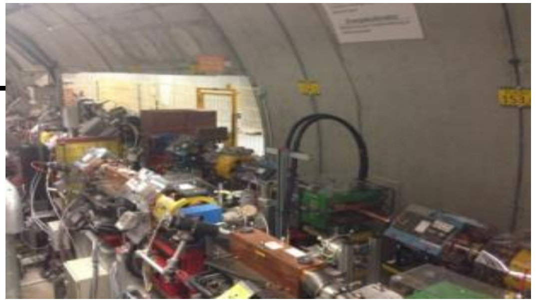
Albert Einstein Hall



FEL Experiments

315 m

Normal conducting 1.3 GHz RF gun
Cs_2Te cathode / 5 injector lasers

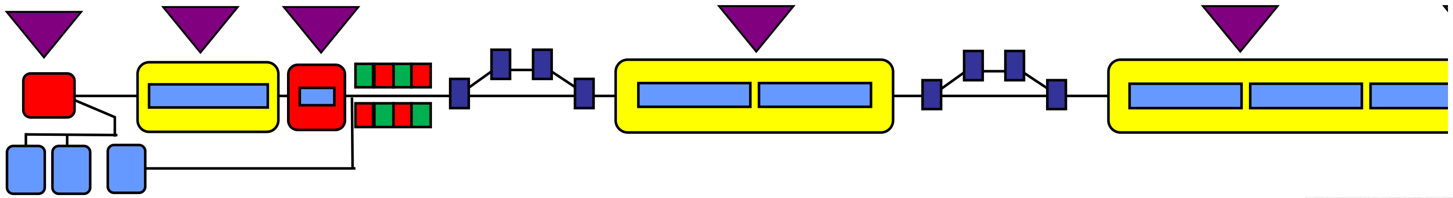


Extraction to FLASH2

Fast orbit feedback

Fast orbit feedback for correction within train

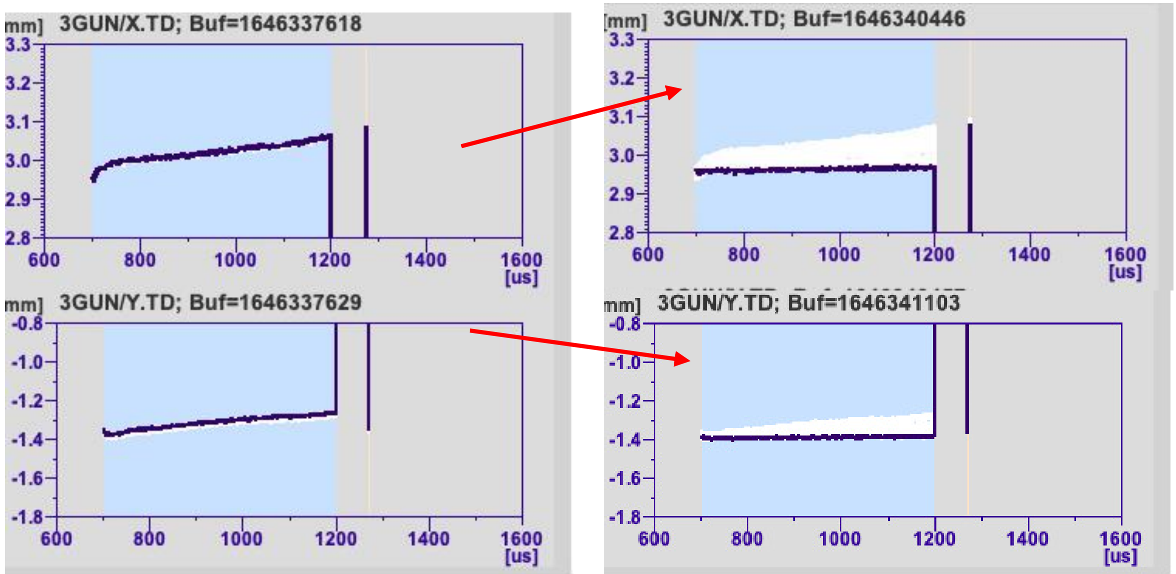
- Total 10 fast kicker magnets
- Use iterative learn control algo.



GUN section
- horizontal:
  KIH1GUN
- vertical:
  KIV1GUN

FL0BC1
- horizontal:
  - KIH2FL0DBC1
  - KIH8FL0DBC1
- vertical:
  - KIV2FL0DBC1
  - KIV8FL0DBC1

FL0BC2
- horizontal:
  - KIH2FL0DBC2
  - KIH8FL0DBC2
- vertical:
  - KIV2FL0DBC2
  - KIV8FL0DBC2

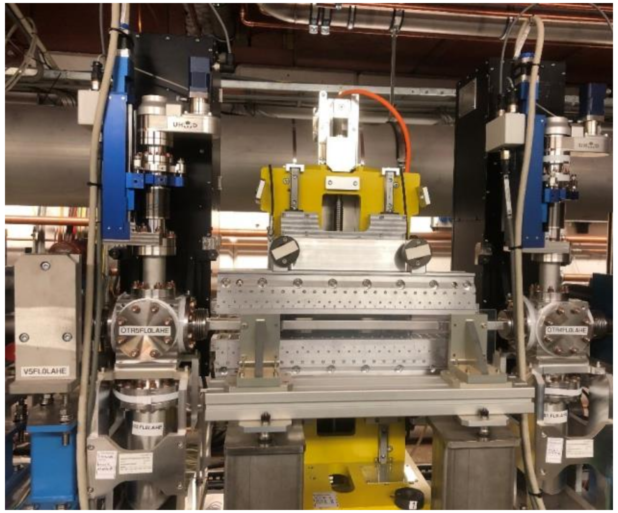


Courtesy: J. Rönsch

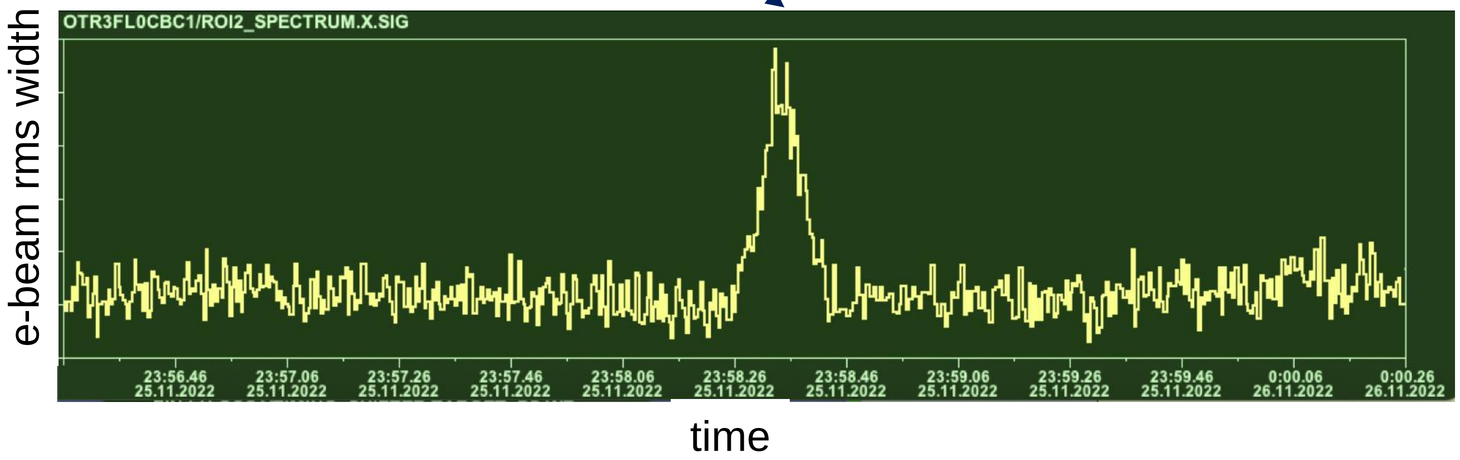
First Bunch compressor (BC1) & Laser heater (LH)

Established machine setting for new BC and LH operation

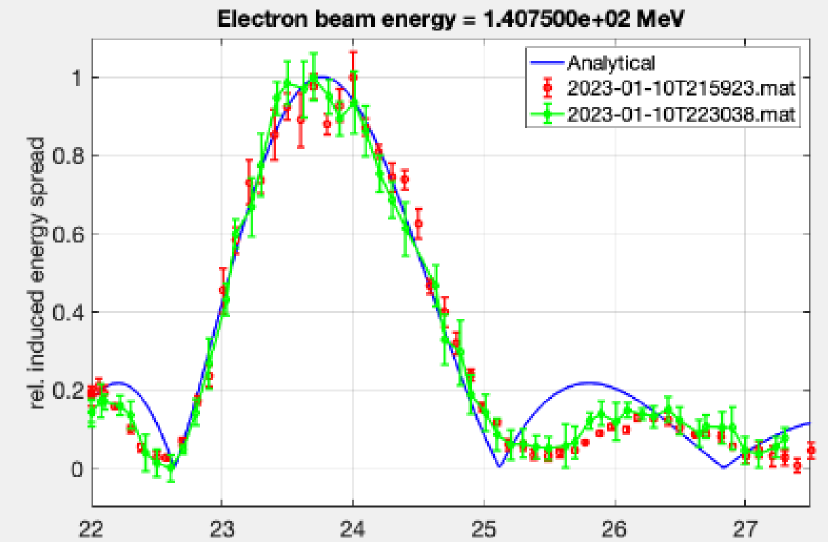
- Reused C-type chicane
  - a new screen and imaging system
  - new default R_{56} ~ 140 mm @145 MeV (former: R_{56} ~ 181 mm @143 MeV)
- Established SASE for new compression settings
- Established LINAC optics with standard LH operation Jan-2023



- Increased energy spread = Temporal overlap



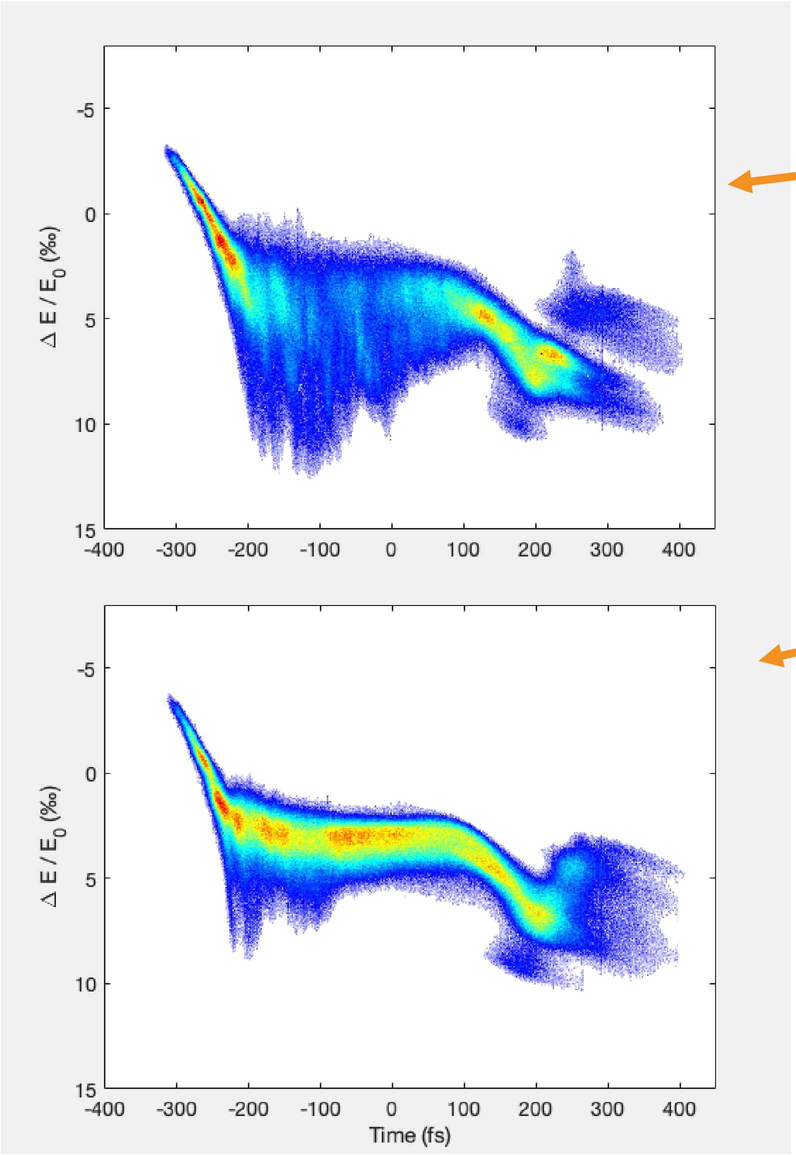
Gap scan: induced energy spread (at OTR in BC1)

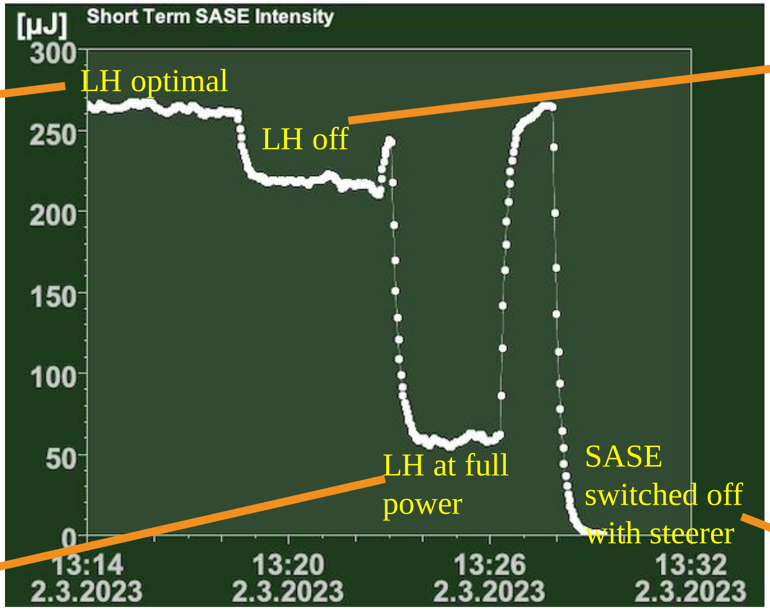


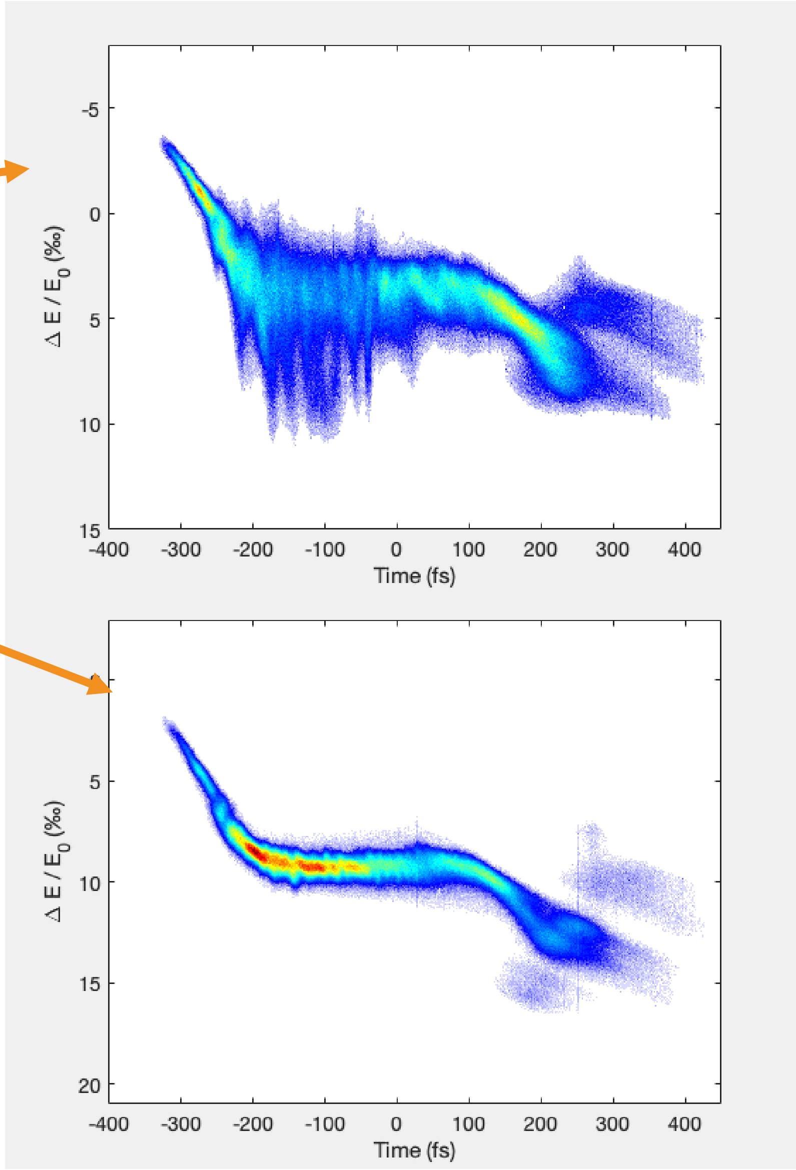
Courtesy: J. Rönsch

Laser Heater (LH) performance demonstration

Example: Studies of influence on SASE







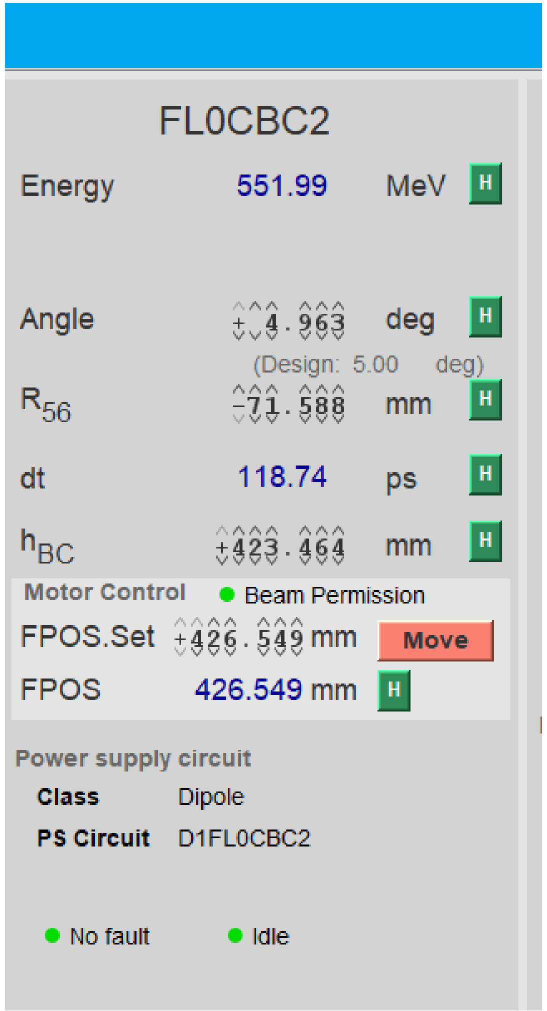
- Optimize laser beamline transport
- Adjusted LINAC optics
- Different studies (microbunching instabilities, machine learning, photon pulse duration, etc.)
- Fix e- orbit at LH undulator

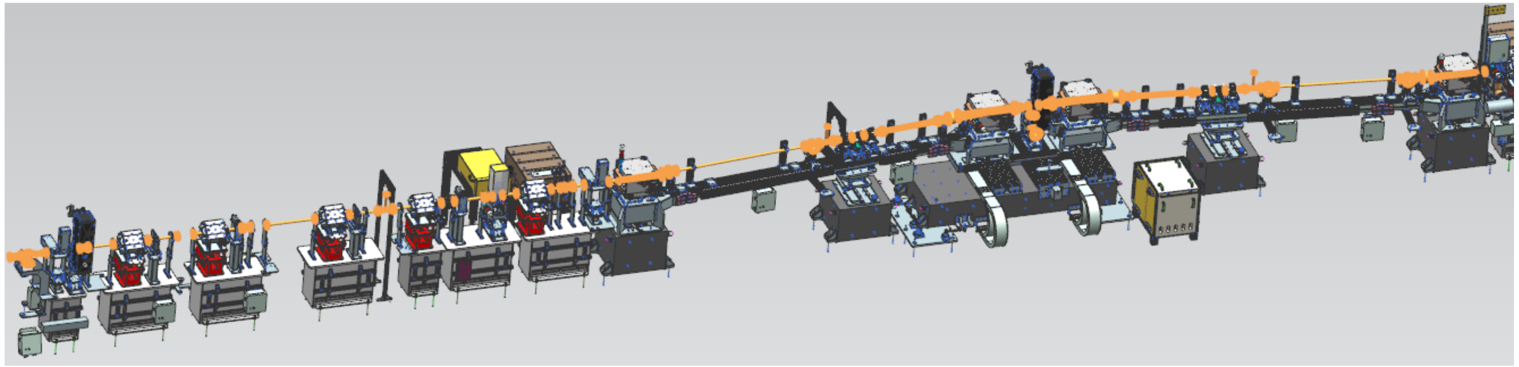
Courtesy: J. Rönsch

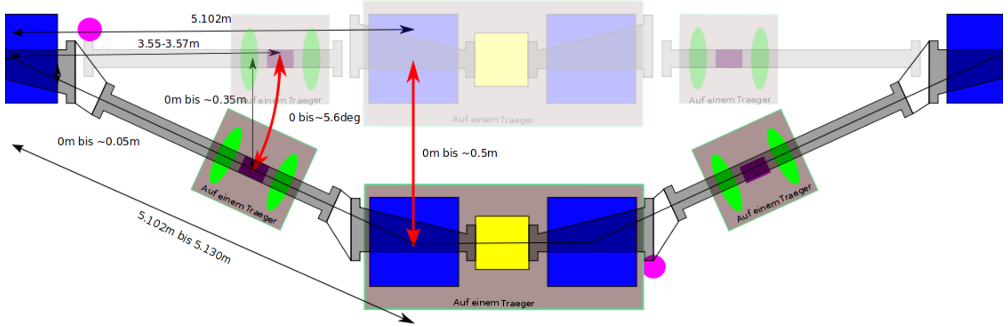
Second Bunch compressor (BC2)

Commissioned standard SASE operation established

- ***Appropriate diagnostic section***: downstream of the second BC using multi quadrupole scans
- **Variable R56** between 0-100mm
- **SASE:** default deflecting angle of 5 deg and with an R56 of ~72 mm.
- **Transverse-longitudinal correction** using quads and skew quads in the dispersive arms to be studied in detail.





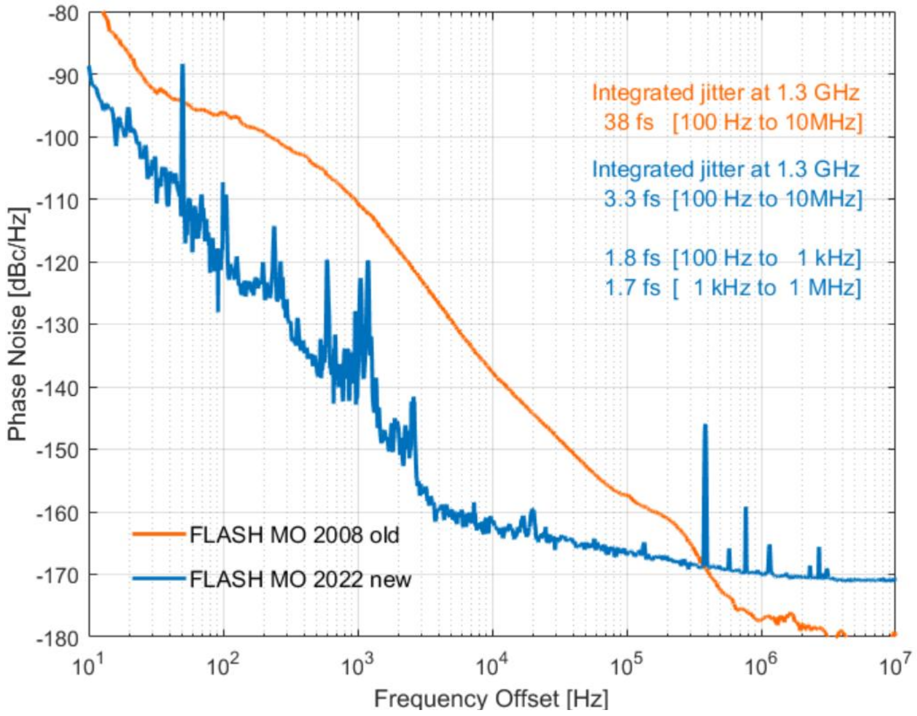


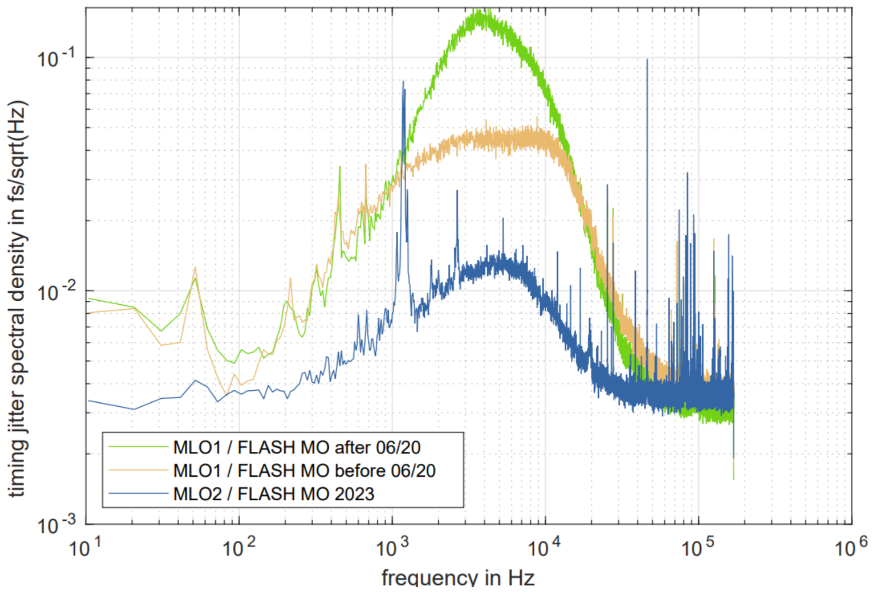
Courtesy: J. Rönsch

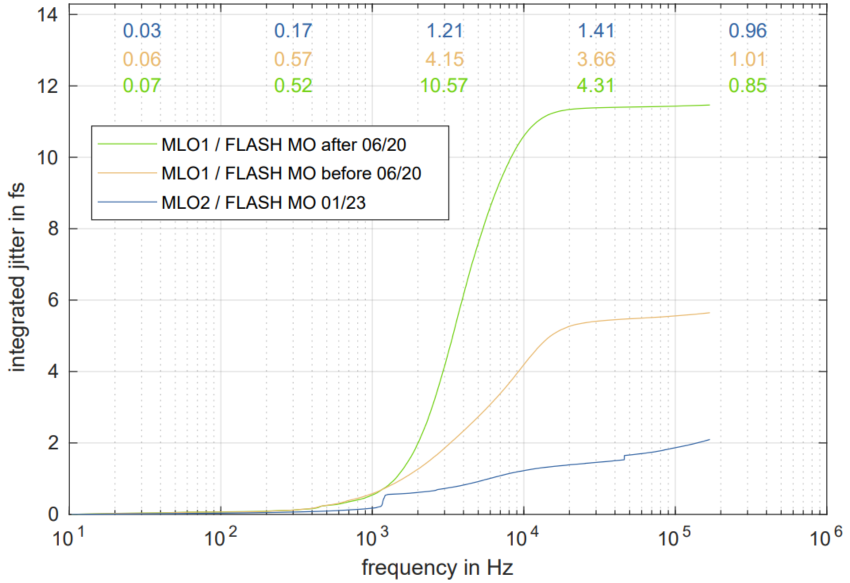
New Master Oscillator & Optical Reference Module

Improved machine stability

- FLASH's main oscillator has been completely redesigned
- Time jitter improved from 38 fs to 3 fs at a high-power RF level of +47dBm
- Master Laser Oscillator synchronized to 2 fs (x 5 improvement)



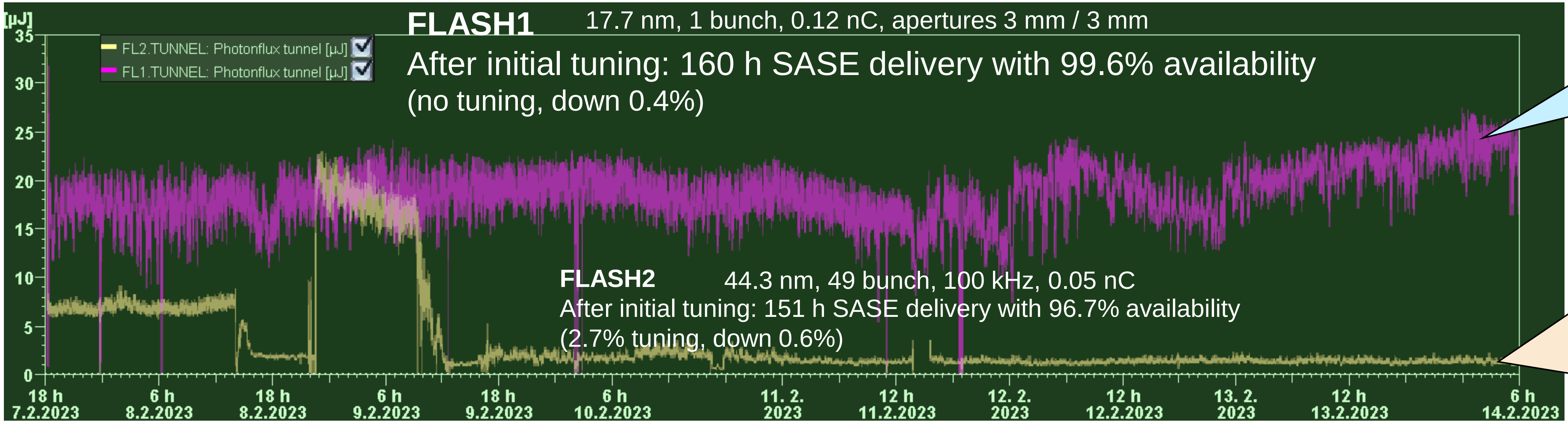




Courtesy: J. Rönsch

Towards 99% availability for user experiments

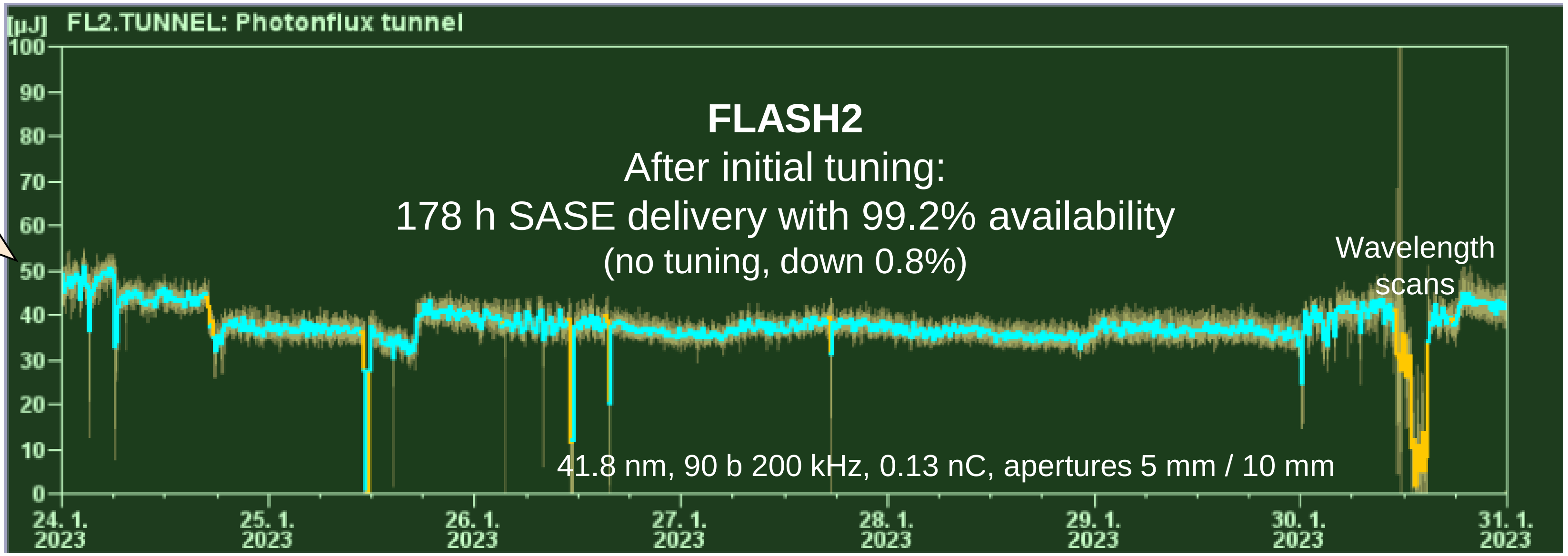
Examples of two experiments in January and February 2023



"the machine reliability during your experiment: good
the quality of the FEL: good"

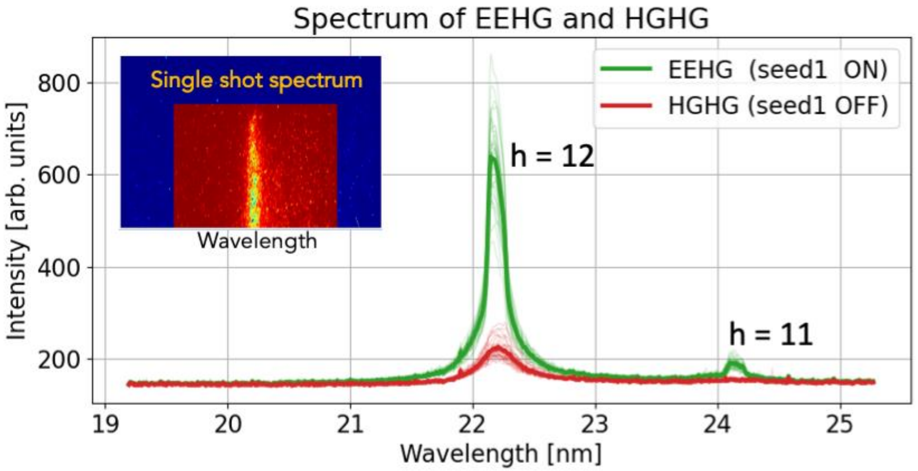
"We had a great week with a great light. The short pulses made the difference (compare to the beamtime of 2020). We would like to thank the machine crew for delivering such a nice beam over the whole beamtime and without interruption."

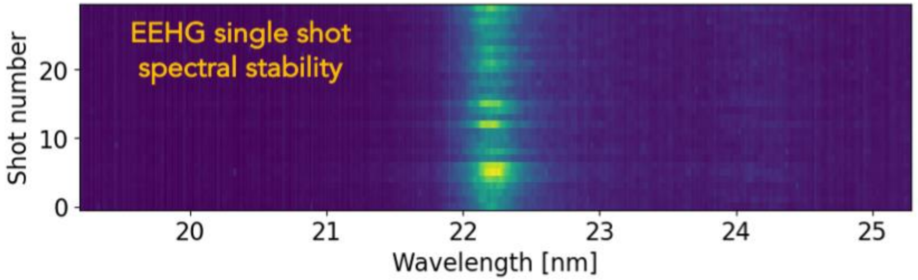
"The performance of the FEL and the pump-probe laser was excellent throughout the beamtime. Except for a few brief periods, the FEL was very stable. All in all, this was a very successful beamtime, and we achieved even *more* than we had anticipated. :-) A big thank you to everyone who contributed on the facility side, and we are hoping to be back for similar experiments in the future!"

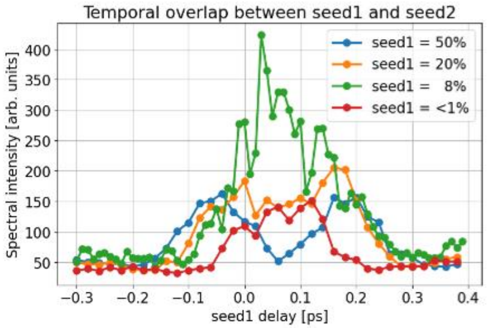


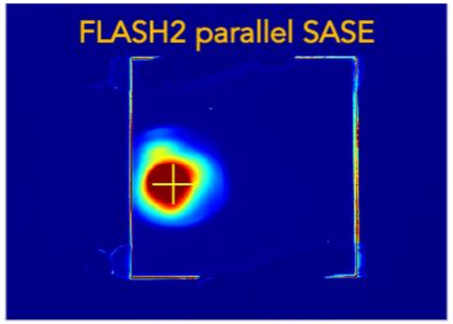
Echo Enabled Harmonic Gain (EEHG) Seeding

Demonstrated reproducible EEGH seeding

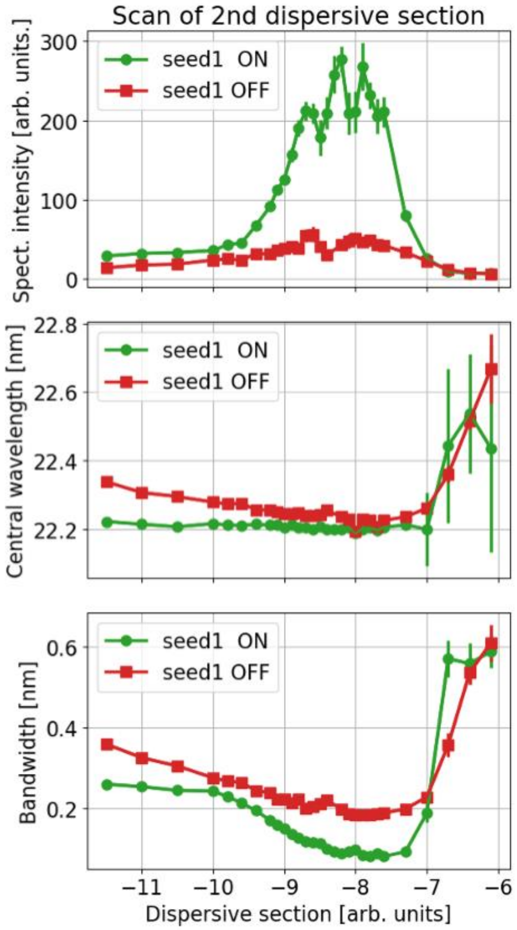


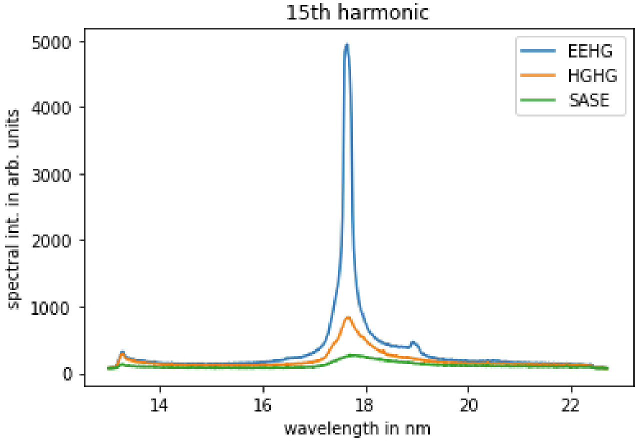






➔ Talk Georgia Paraskaki





- Successful EEHG seeding at FLASH1
- EEHG seeding was reproducible in a 2nd shift block after 4 days with a fantastic quick set-up of 4 h
- 9th, 15th, 17th harmonic seen
- 2nd bunch works as the 1st one – multi bunch!
- All time with good SASE at FLASH2

Courtesy: J. Rönsch

FLASH2020+

Project Update

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

New scientific demands for Free Electron Lasers

DESY survey on new requirements for soft-X ray FELs

User's „dream machine“	Scientific purpose	FLASH2020+ plans	FEL line
Extended wavelength range	Reach O and N K-edges and 3d metal L-edges	Increase accelerator energy, use advanced undulator schemes	FLASH2
Variable polarisation	Circular dichroism for magnetism and chirality	Flexible APPLE-III undulators and afterburner	FLASH1 and FLASH2
Flexible pump-probe schemes	Resonant excitations	Flexible schemes with optical laser and FEL options for multi-colour pump-probe experiments	FLASH1 and FLASH2
Fourier-limited pulses	Stable, small bandwidth spectroscopy and coherence applications	Laser-manipulation of electron bunches at 1MHz: **Seeding**	FLASH1
Ultrashort pulses at 1fs and shorter	Ultimate temporal resolution, highest power	New undulator combinations	FLASH2
CW operations (100kHz)	Low hit rate experiments	*Postponed as long-term goal (2030+)*	

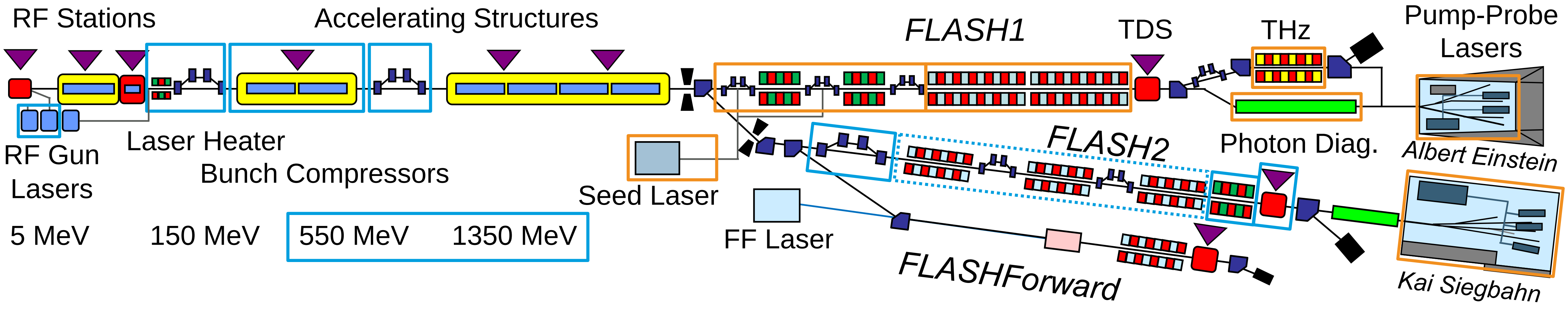
Courtesy: L. Schaper

FLASH2020+

Modifications to the facility

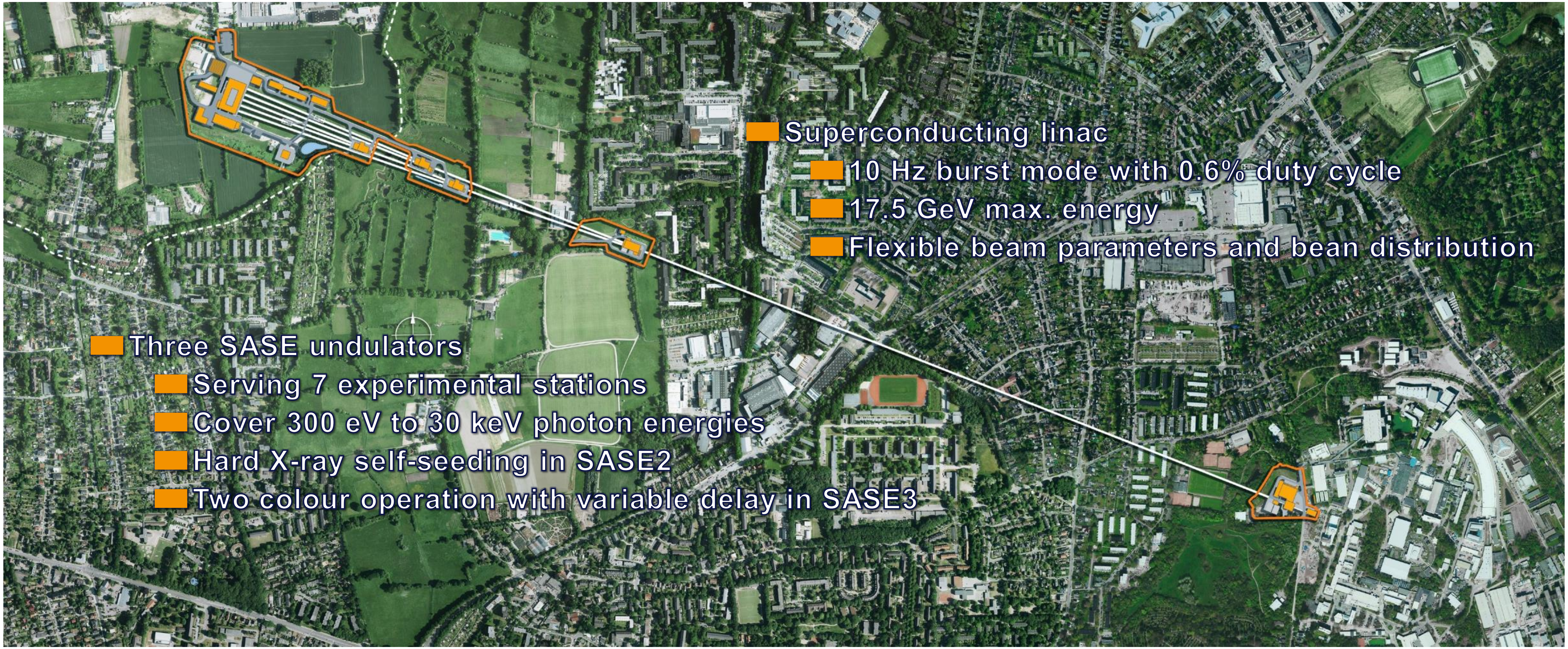
Tackled		Upcoming	Future (not funded yet)
3rd BC FLASH2	New bunch compressors (linac)	High rep. rate seeding (FLASH1)	New undulator schemes (FLASH2)
TDS (FLASH2)	Variable gap undulators (FLASH2)	Photon diagnostics (FLASH1)	New lasing concepts (FLASH2)
Energy upgrade	Interim pump-probe laser (FLASH1)	THz Source	
Laser heater	New beamline FL23 (FLASH2)	Flexible pump-probe lasers	
Injector laser	Afterburner FLASH2	New beamlines	

✔ Secured additional funding for reduced sub-synchronization



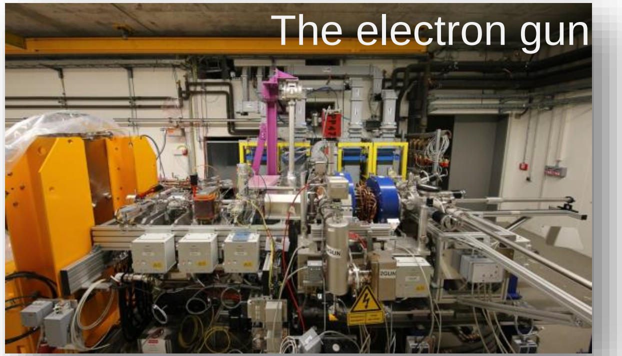
European XFEL

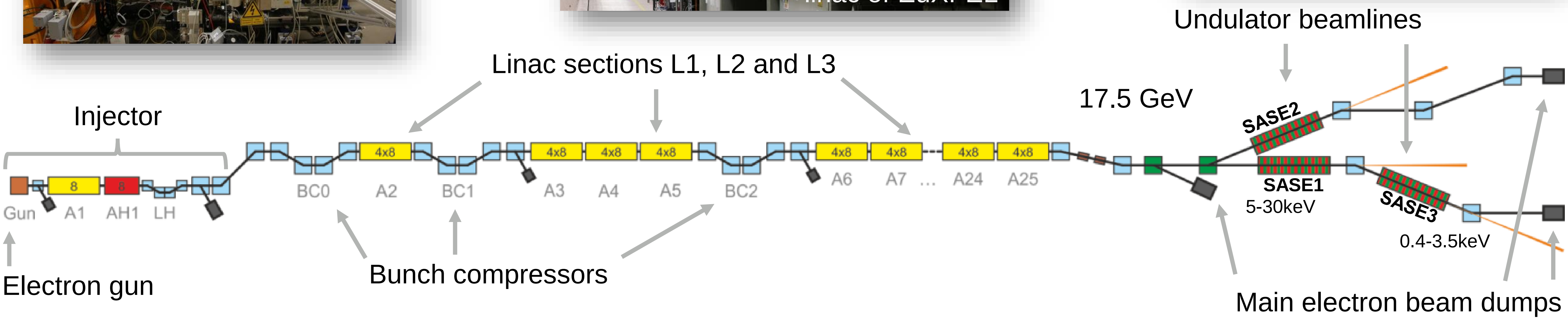
European XFEL



Courtesy: W. Decking

EuXFEL Accelerator





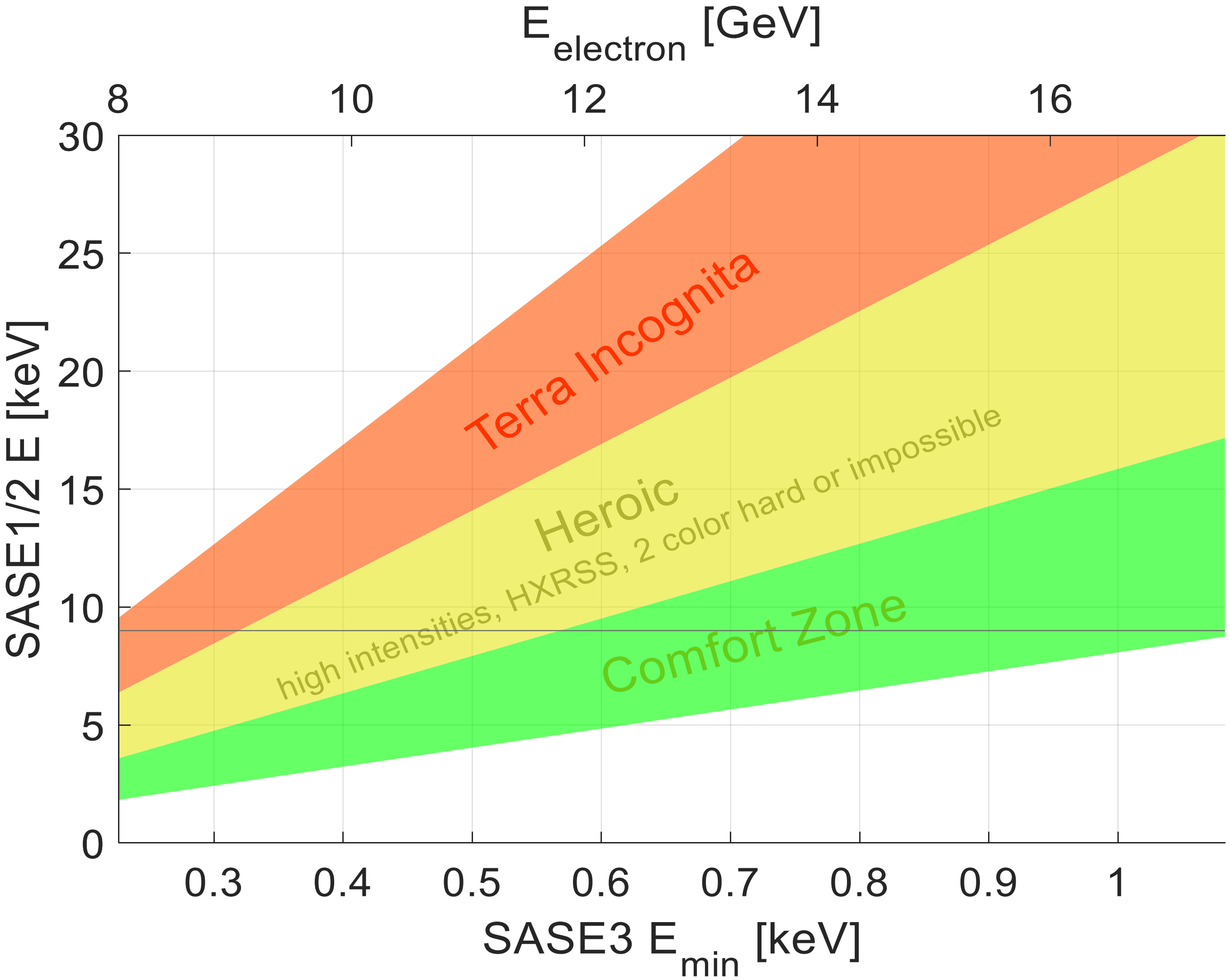
The electron accelerator is operated from the DESY campus in Hamburg Bahrenfeld.

The photon beamlines and photon diagnostics as well as the instruments are operated from the EuXFEL campus in Schenefeld.

Courtesy: W. Decking

EuXFEL can provide FEL radiation from 300 eV to 30 keV

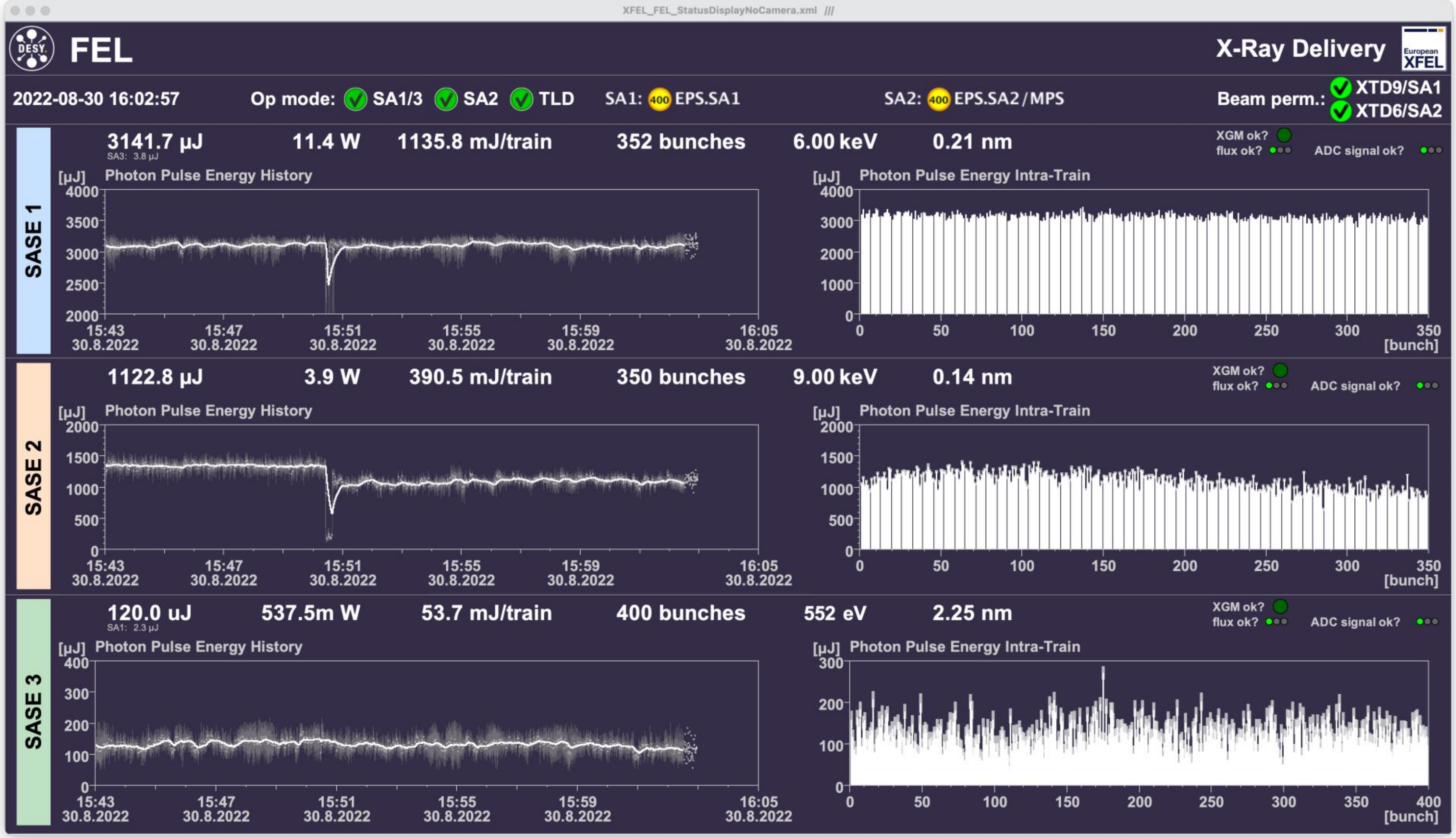
- SA3 minimum photon energy determines required electron energy
- Small electron energy strongly influences hard X-ray FEL performance
- Scheduling issue



SASE3: λ = 68 mm, K = 8.9 – 4
SASE1/2: λ = 40 mm, K = 3.8 – 1.1

Courtesy: W. Decking

Long pulse trains

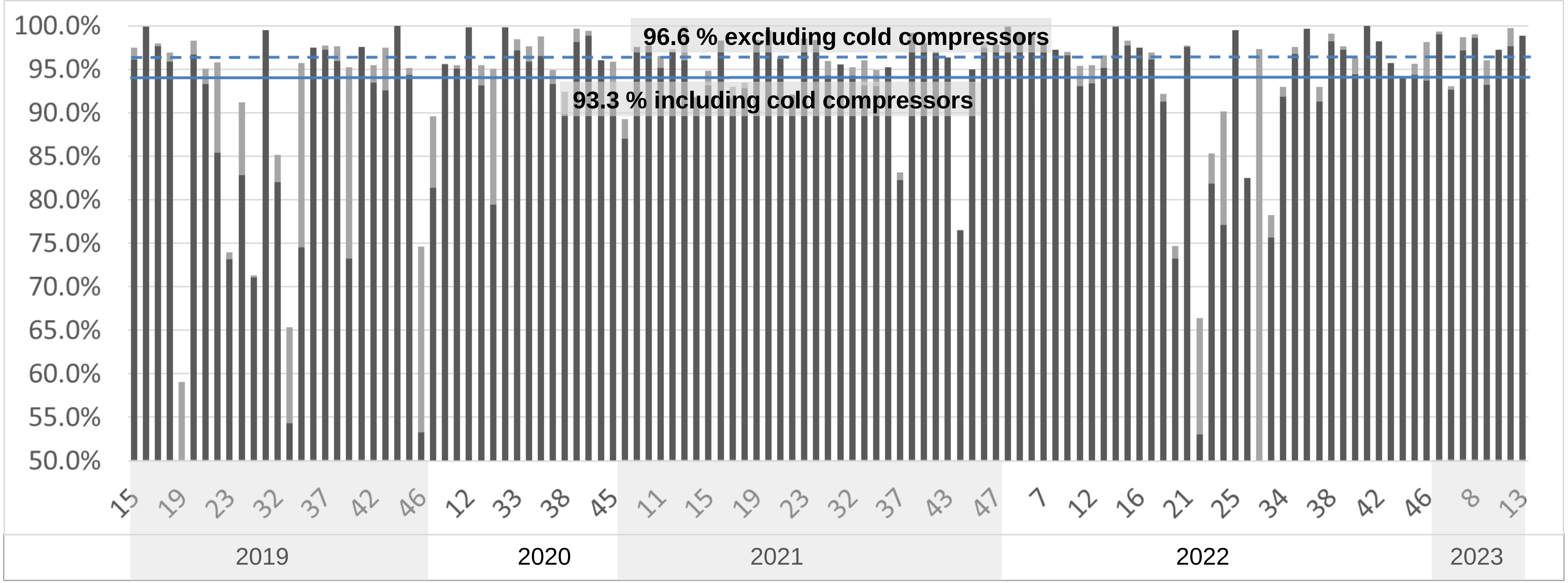


Many bunch capabilities of European XFEL are more and more apparent during user runs.

Here a total of 1142 pulses lasing at the same time

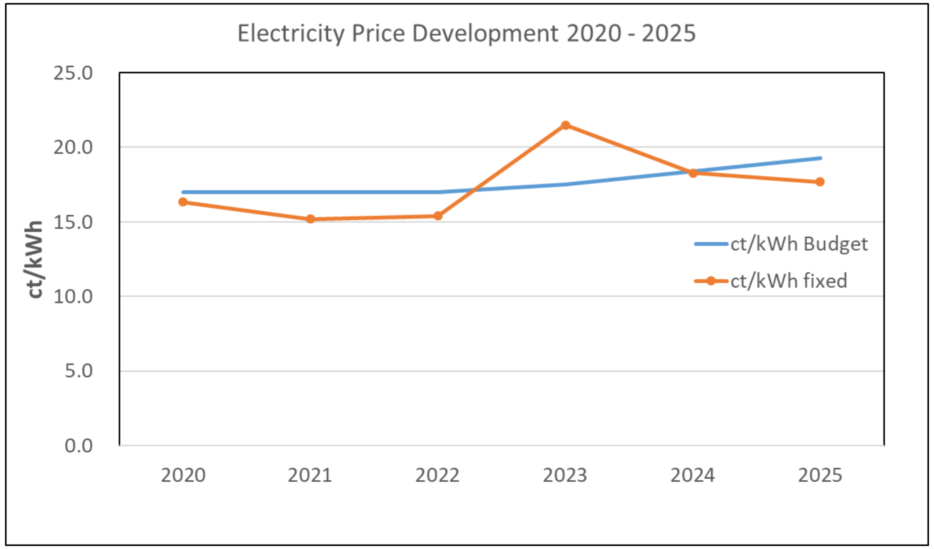
Courtesy: W. Decking

Availability during 16.850 hours of X-Ray Delivery

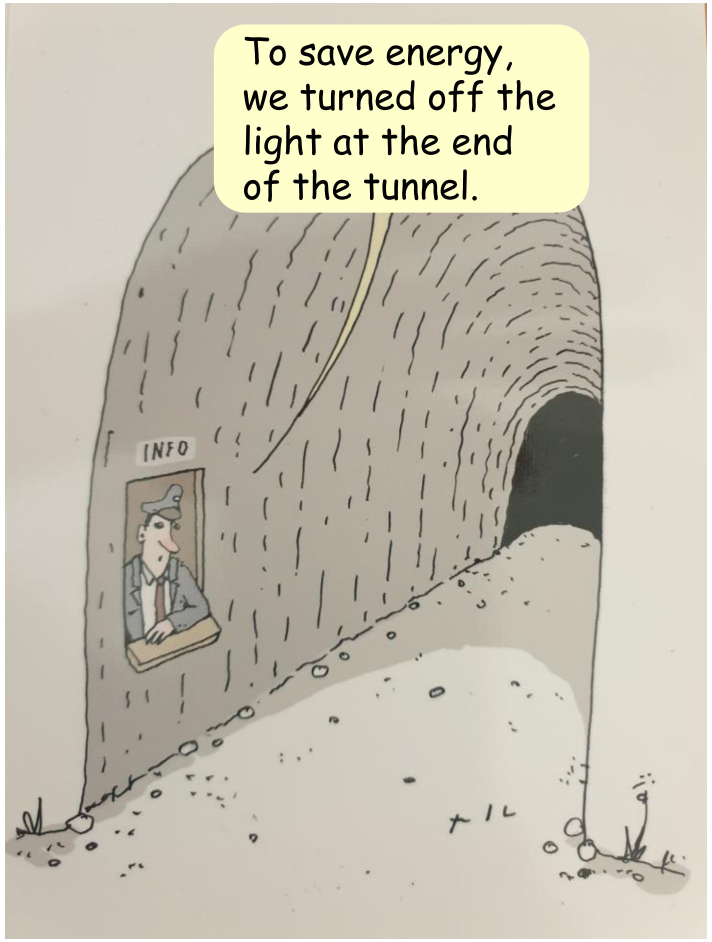


Courtesy: W. Decking

Electricity Cost



- Electricity consumption overall facility **about 90 GWh**
- DESY/EuXFEL buy electricity at the European Energy Exchange
- Achieved price is often below budgeted value
- 2023 price peak can be covered with available operations funds
- In addition energy savings in linac operation will reduce overall electricity consumption



Courtesy: W. Decking

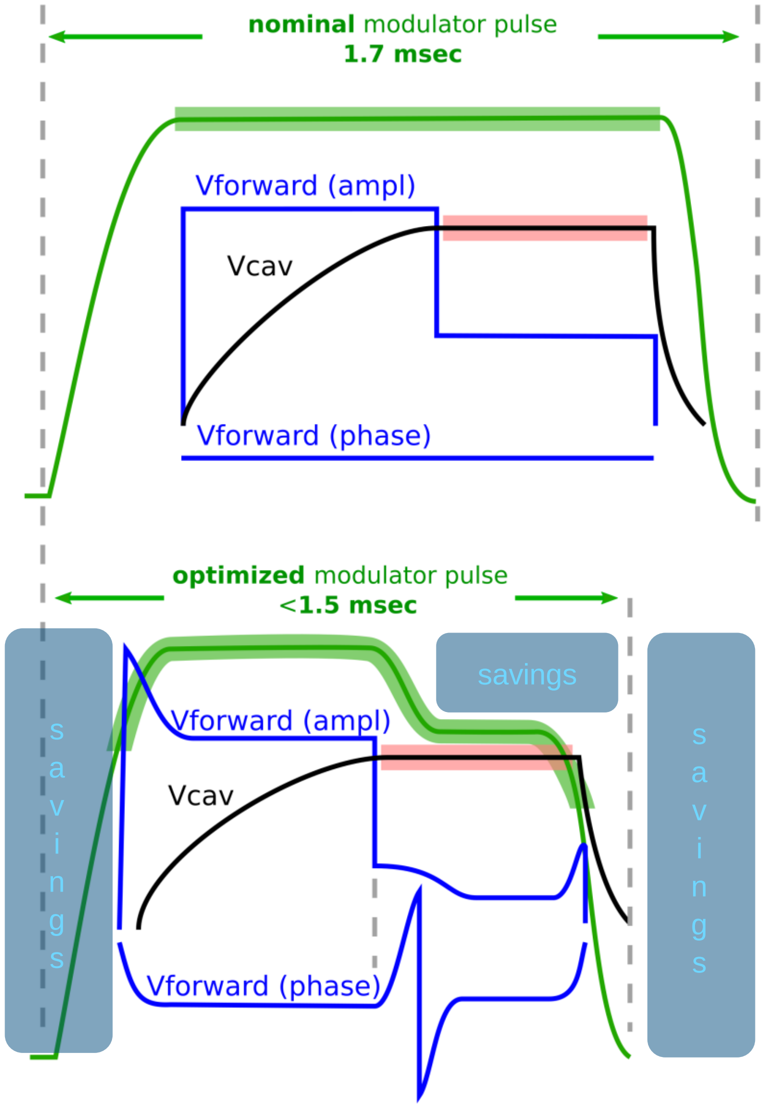
LLRF & RF development

to reducing energy consumption

- **Remove overheads**
  - Lowering modulator high voltage (e.g. at 14 GeV)
  - User rising times
  - Use fall times
  - Shaping modulator voltage during flat top

  ➔ Potential energy saving **20% up to 30%** (depending on station)

- Savings increased **complexity for RF control** and **longer setup time**
- But very promising preliminary tests (**robustness** and **performance**)



Courtesy: J. Branlard

Short photon pulses

a) Variable Charge

- Injector laser pulse can be ‘modulated’ with 4.5 MHz, thus providing different bunch charges within the train (FLASH uses 2nd laser for this)
- Thus can also work in interleaved mode
- Available in test operation in 2nd half of 2023

b) Non-linear compression (~ 10 fs)

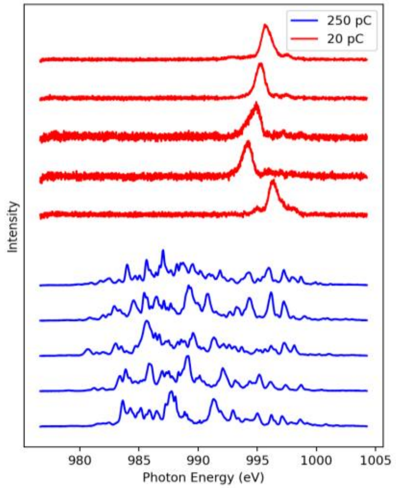
- Beam regions allow for individual compression along bunch train
- Because of high quality factor of SC cavities can only be applied in non-interleaved mode
- Available in non-interleaved modes

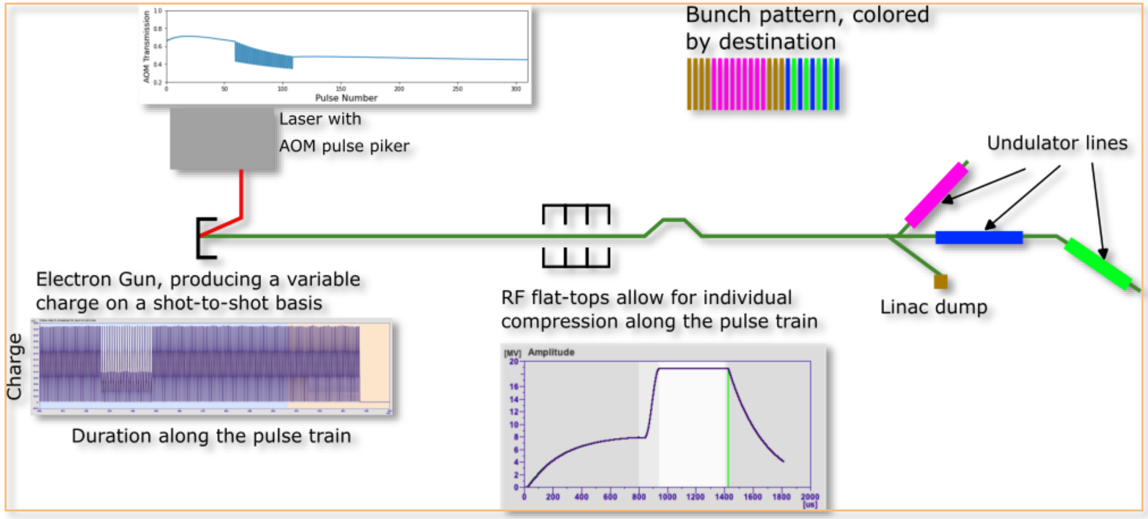
c) Low charge + NL compression + dispersion (< 1 fs)

- Very short bunches

d) Wakefield-based fresh-slice (fs level)

SASE3 photon spectra for low and nominal charge operation with optimized compression (i.e. combine a & b)

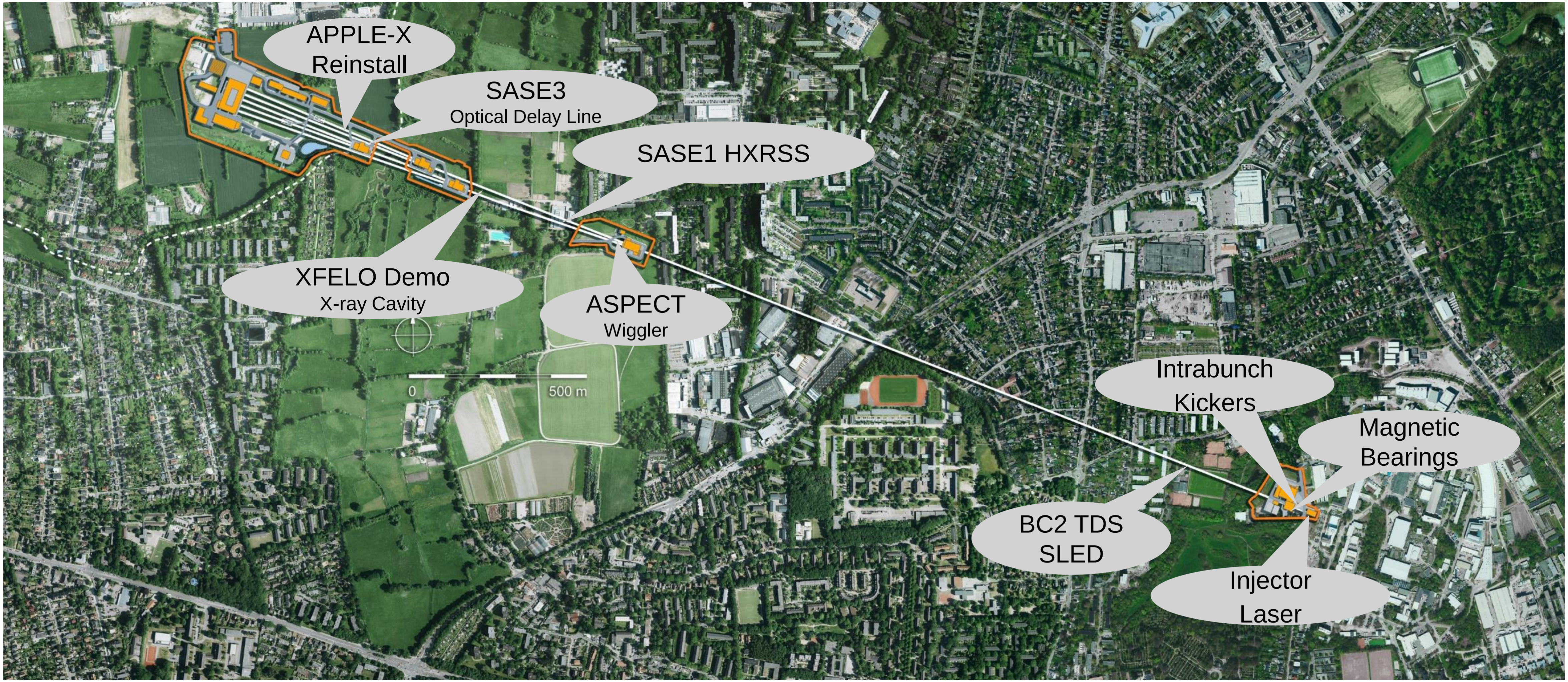




Short bunch methods using injector laser and RF manipulations

Courtesy: W. Decking

2023 - 2025: 4-6 weeks/year Installations - Overview



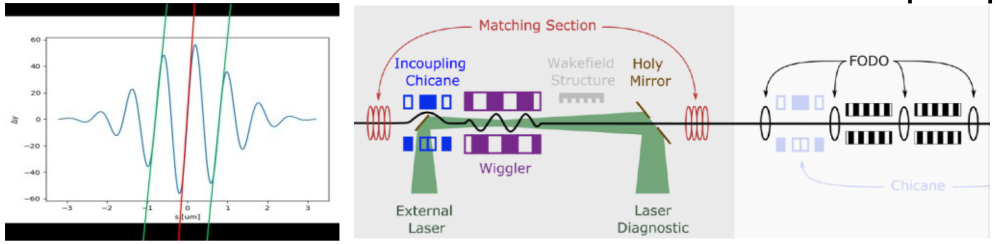
Courtesy: W. Decking

Source Developments

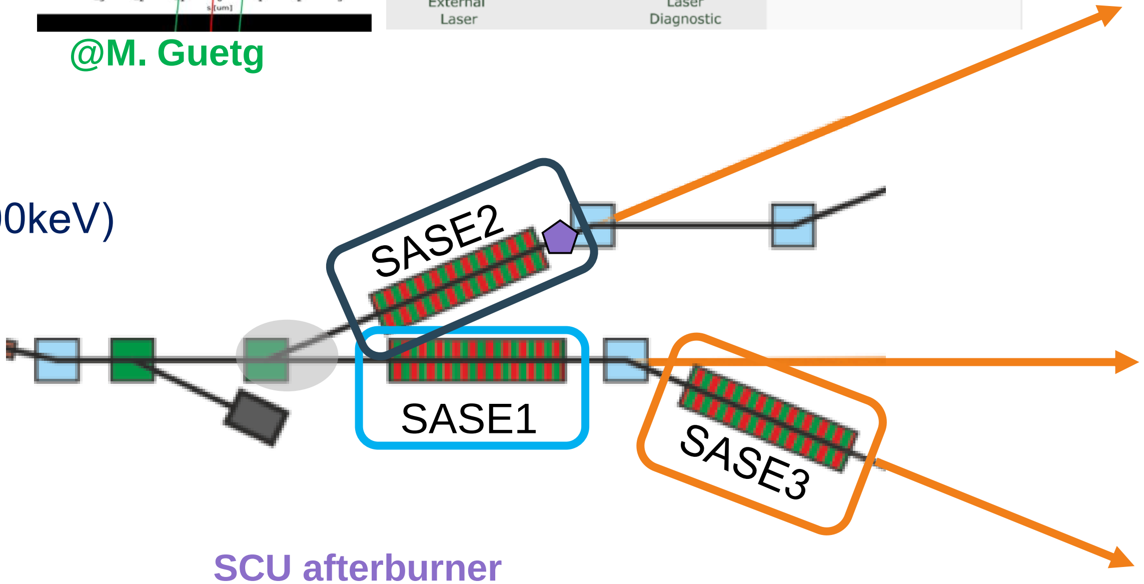
- **SASE1:**
  - Corrugated structure in 2022/23
  - ASPECT for short bunches at SASE1/SASE3
  - XFEL Oscillator demo in 2023
  - HXRSS under discussion
- **SASE2:**
  - Superconducting undulator as afterburner 2025-2027 (…100keV)
  - 2 color fresh-slice under development
  - HXRSS for larger wavelength range
- **SASE3:**
  - APPLE-X commissioning
  - Corrugated structure in 2022/23
  - ASPECT for short bunches at SASE1/SASE3
  - Optical delay line for more flexibility on 2 color operation

➔ Talk Marc Guetg

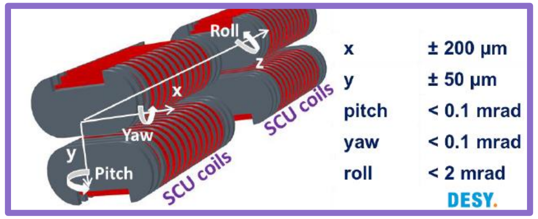
ASPECT: AttoSecond Pulses with eSASE and Chirp/Taper



@M. Guetg



SCU afterburner



SPRESSO
SUPERCONDUCTING UNDULATOR PRE-SERIES MODULE

@S. Casalbuoni

Courtesy: W. Decking

R&D Program – some examples

- CW SRF and HDC uprade:

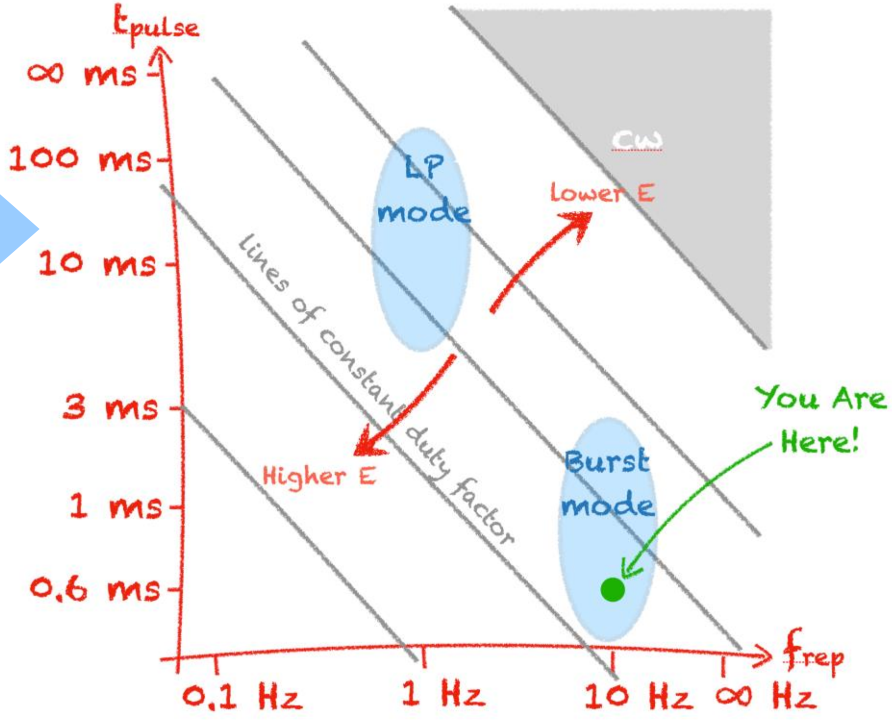
CW	CW modules	
CW	SC CW gun	
CW	NC CW gun	
CW	Basic CW gun research	
CW	Photo cathode laser shaping	
CW	CW LLRF Development	
CW	Nano-structured Cathodes	*New*

- IPCROB:

IPCROB	Marwin	
IPCROB	DAQ Data Mining	

- Advanced Accelerator Concepts:

AAC	DemoFEL	*New*
AAC	Plasma Booster	*New*



Courtesy: W. Decking

Thanks to

Michaela Schaumann, Riccardo Bartolini, Ilya Agapov, Harald Reichert, Siggi Schreiber, Katja Hoonkavara, Juliane Roensch, Winni Decking, Julien Branlard, Riko Wichmann, and many more …

for material