Facility Report – DESY –

ARD-ST3 Annual Meeting 2021

Holger Schlarb, Group Leader MSK/DESY
DESY, Hamburg, 29. September 2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

DESY activities : birds view …

PETRA III & IV

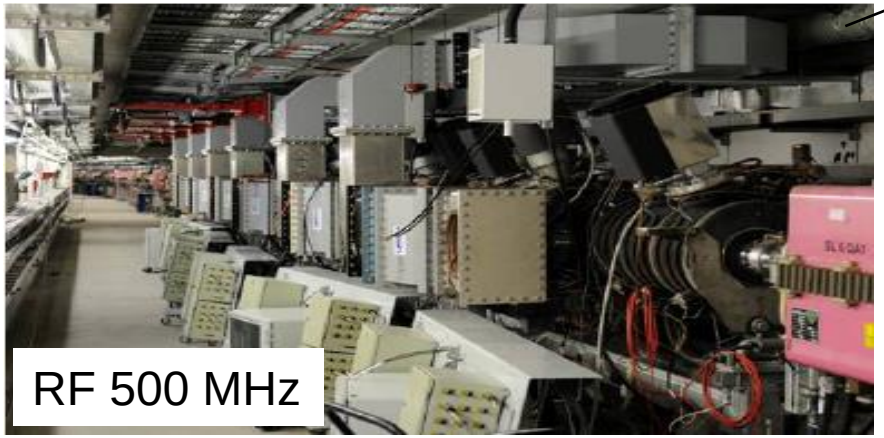
PETRA III

Courtesy: R. Wanzenberg

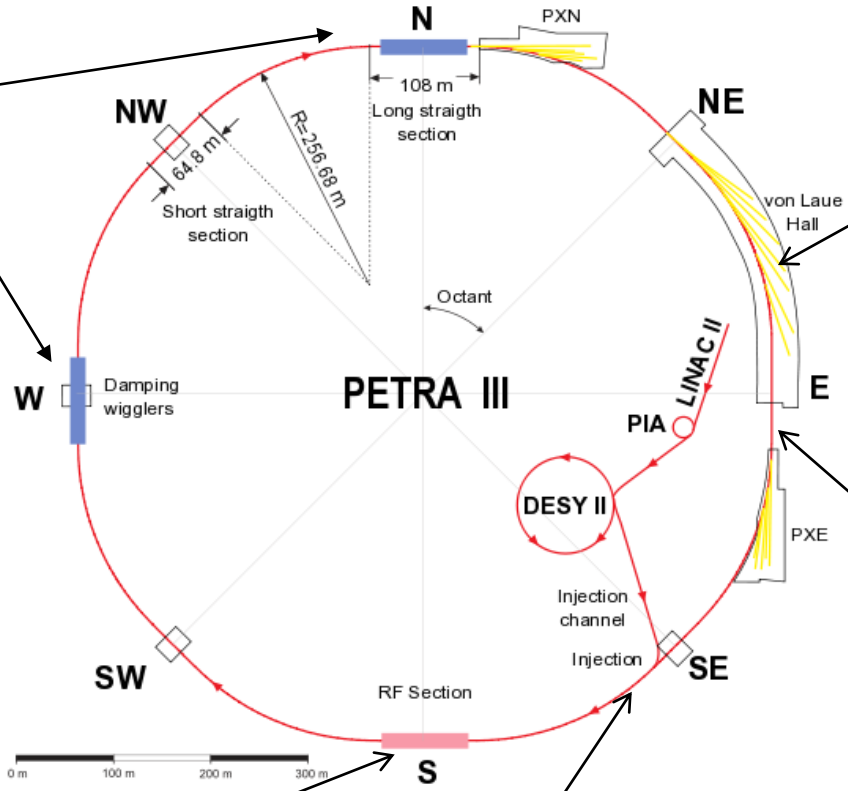
Wigglers 80m

ε_x: 5 nm → 1.2 nm

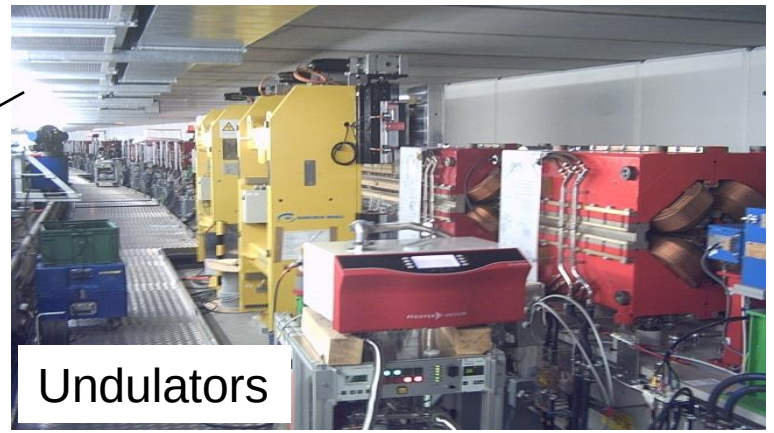
FODO Arc



RF 500 MHz



Injection



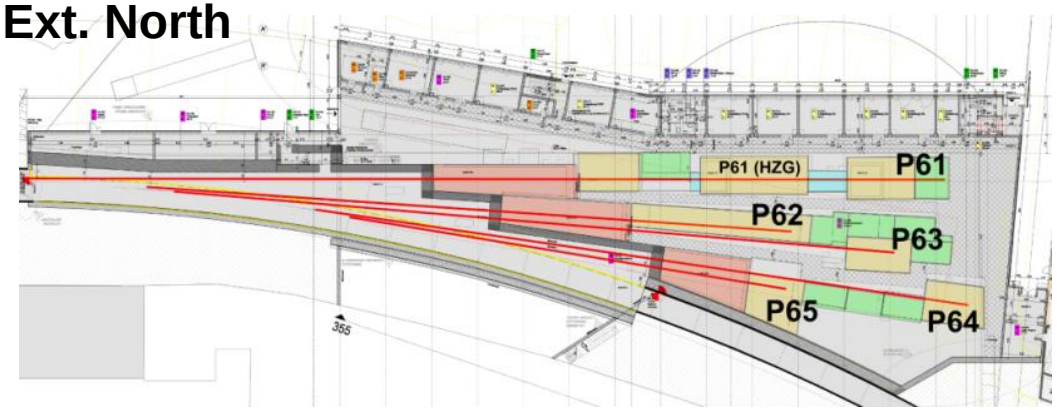
Undulators

Long. MBFB Feedback

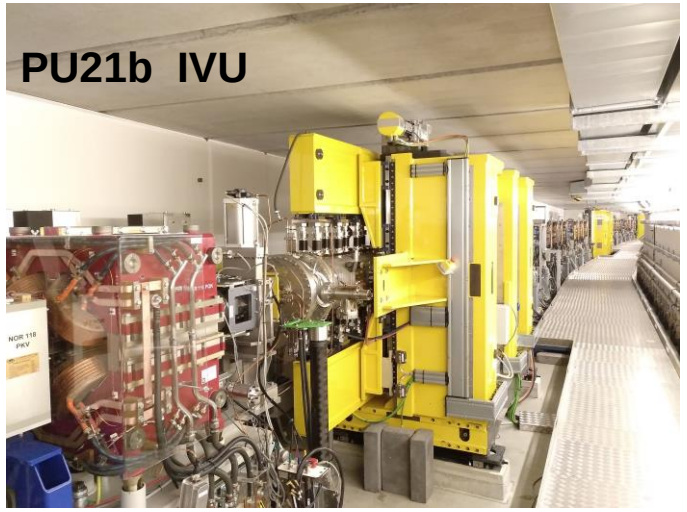
Parameter	PETRA III	
Energy / GeV	6	
Circumference /m	2304	
Emittance (horz. / vert.) /nm	1.2 / 0.012	
Total current / mA	100	
Number of bunches	960	40
Bunch population / 10^{10}	0.5	12
Bunch separation / ns	8	192

PETRA III

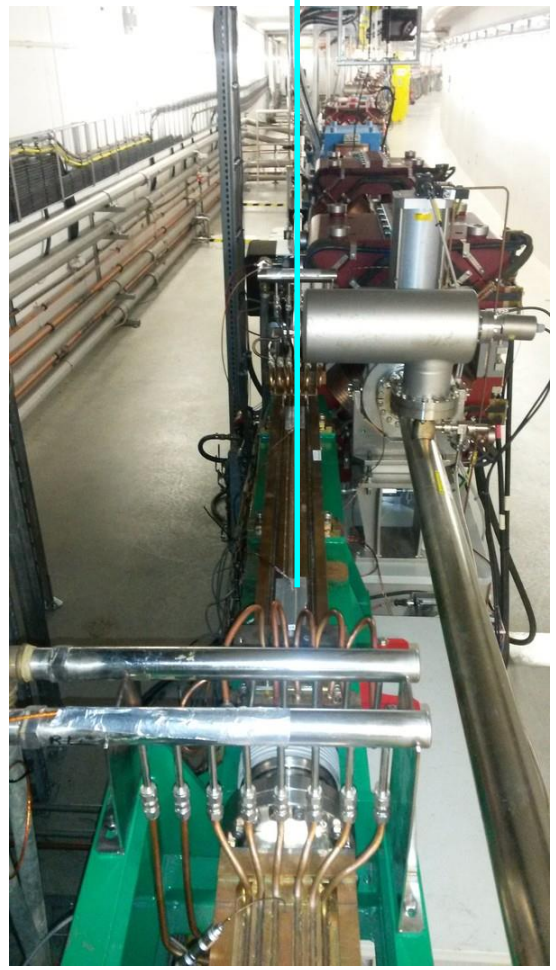
Ext. North



P21 b/a: In vacuum undulator



To beam line P61



P66 superlumi dipole beamline

Courtesy: R. Wanzenberg

PETRA IV.
NEW DIMENSIONS

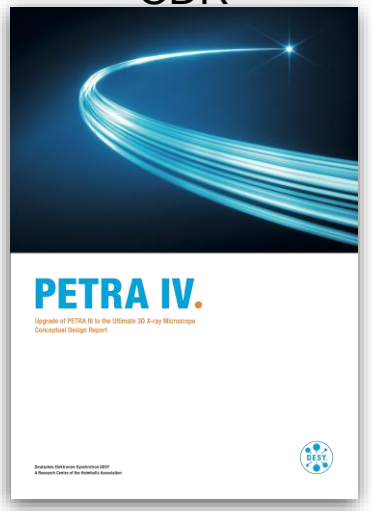
Project Status: TDR phase

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

Riccardo Bartolini

PIV Project Management

CDR



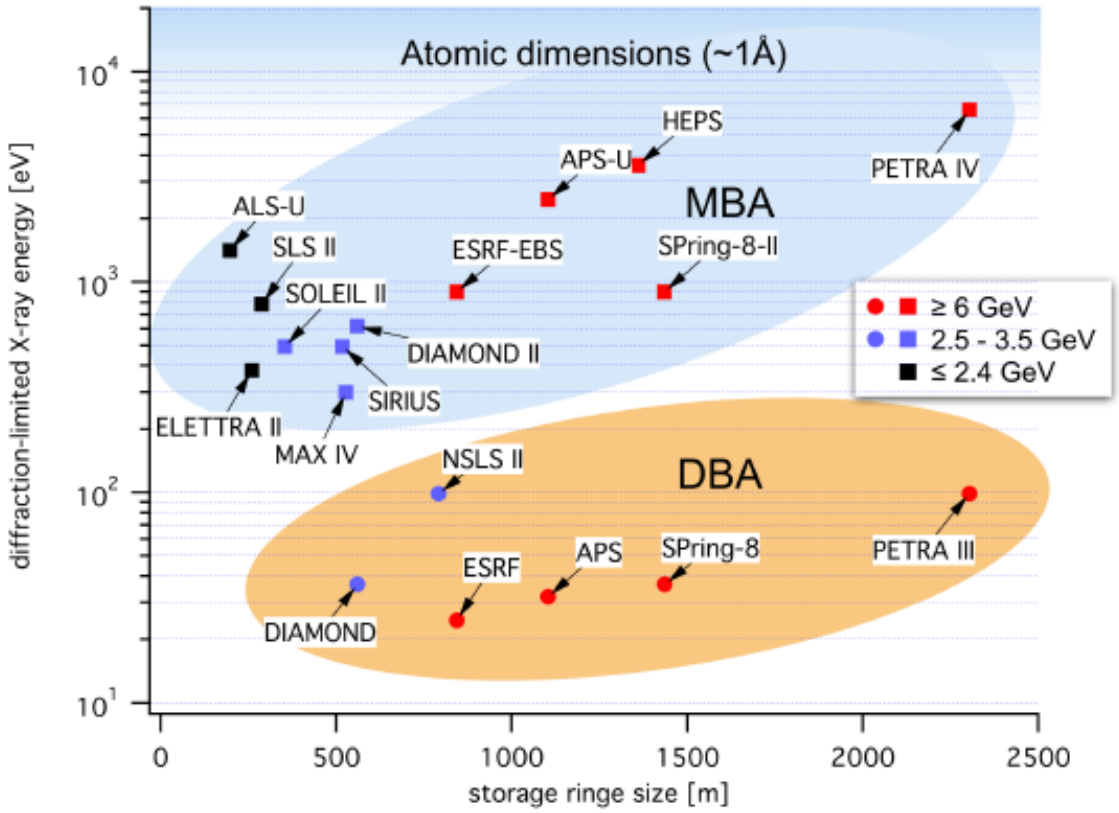
DOI: 10.3204/PUBDB-2019-03613

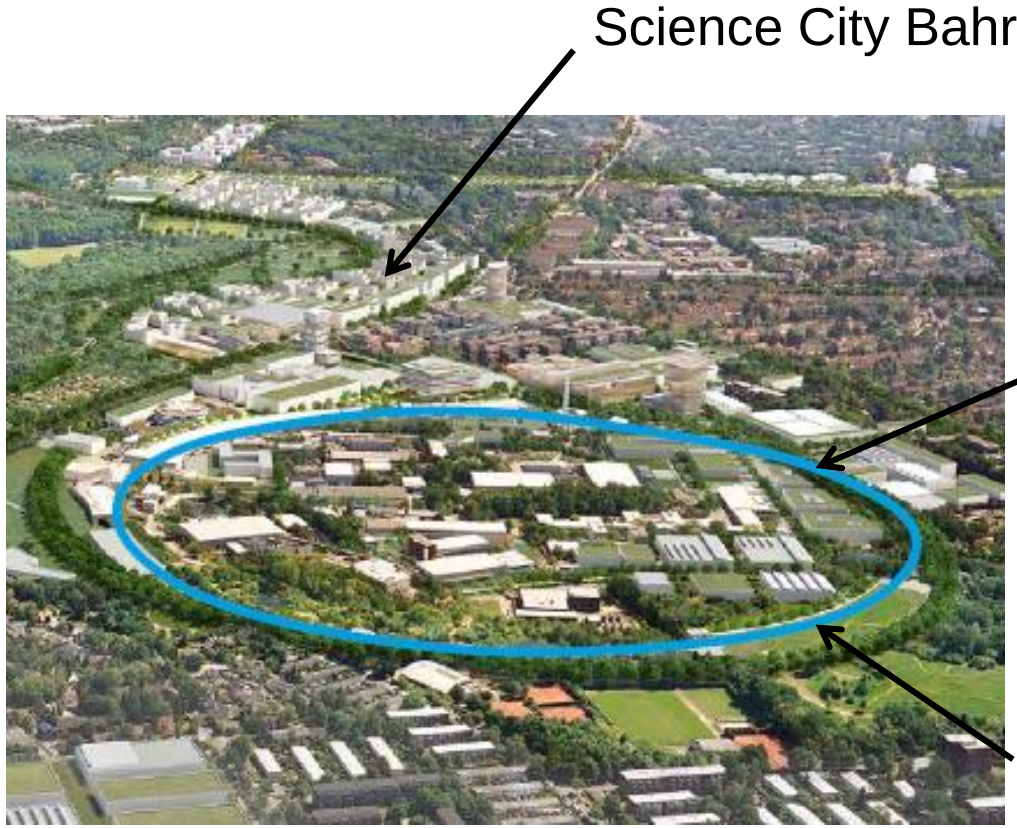
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

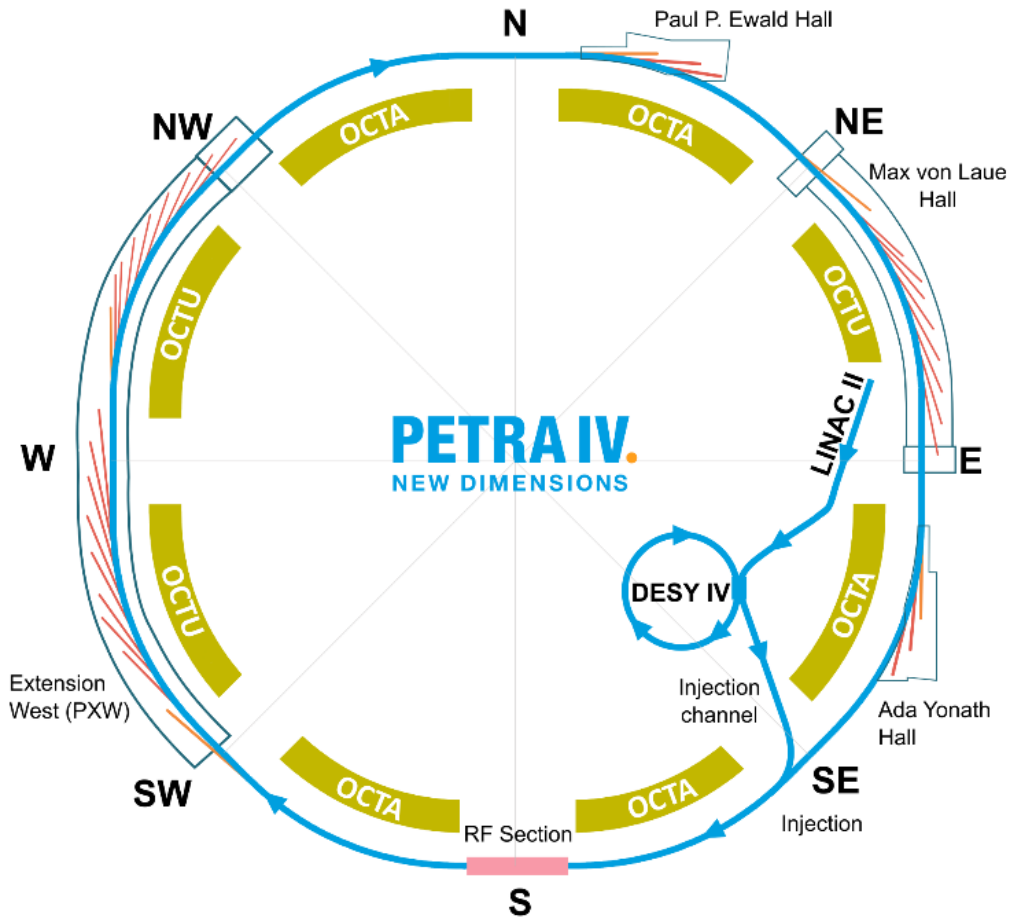
PETRA IV

- 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



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

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

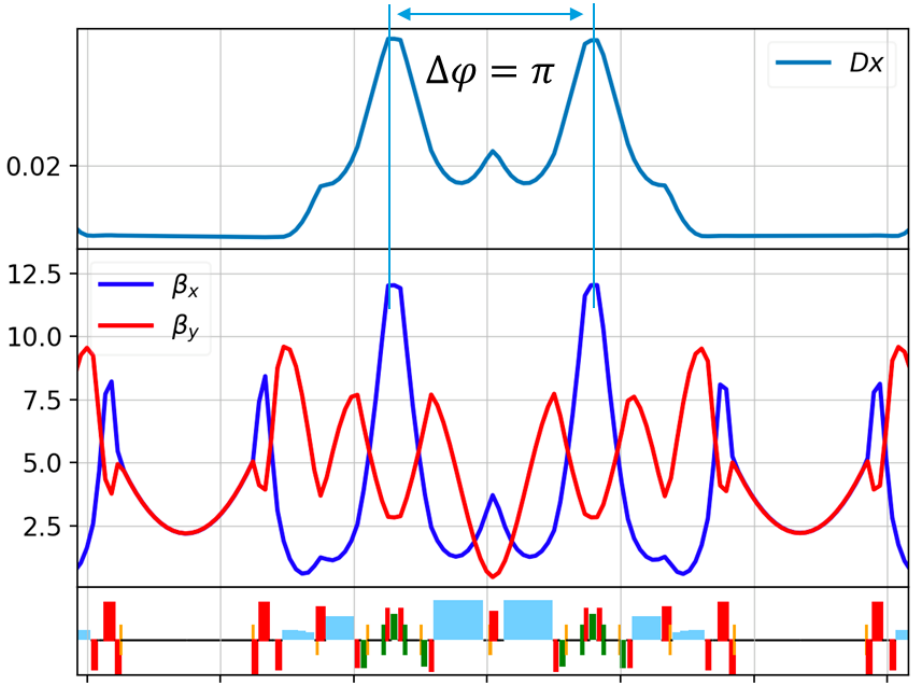
	H6BA	Combi (H7BA)
Tunes ν_x, ν_y	135.18, 86.27	154.18, 66.27
Natural chrom. ξ_x, ξ_y	-233, -156	-200,-170
Mom. comp. α_C	$3.3\ 10^{-5}$	$1.8\ 10^{-5}$
U_0	4.17 MeV	3.9 MeV
Standard ID section	4.7 m	5.3 m
Hor. Emittance w/o IDs, zero current	20 pm	18 pm
Hor. Emittance with IDs, zero current	20 pm	9.2 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

Courtesy: R. Bartolini

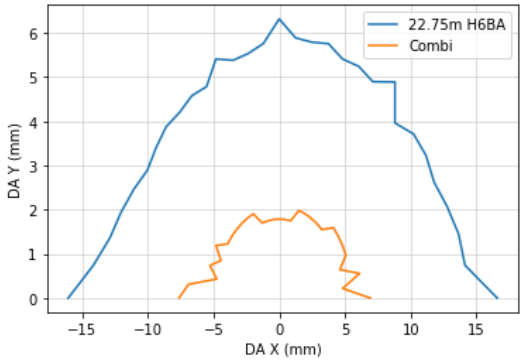
PETRA IV H6BA lattice

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

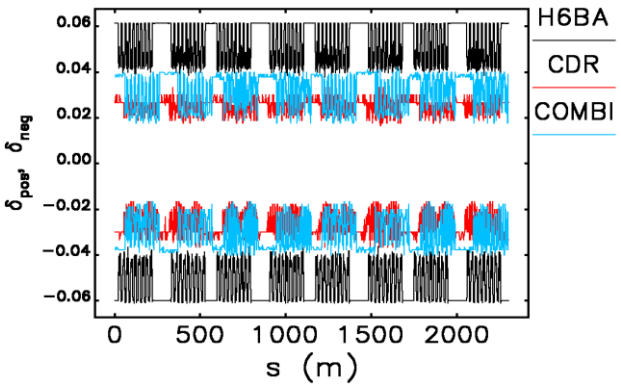
+ 40 damping wigglers → recover 20 pm emittance goals



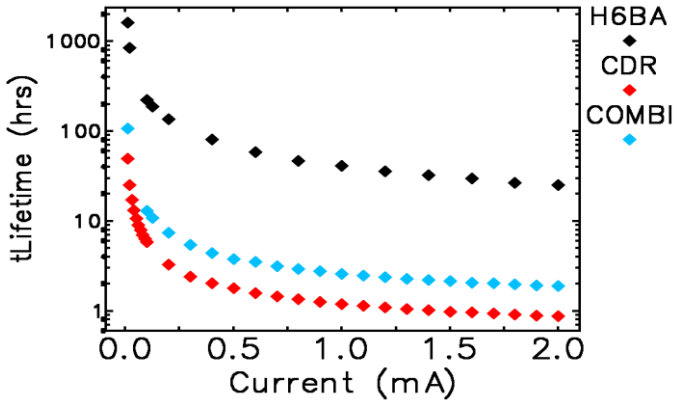
Dynamic aperture



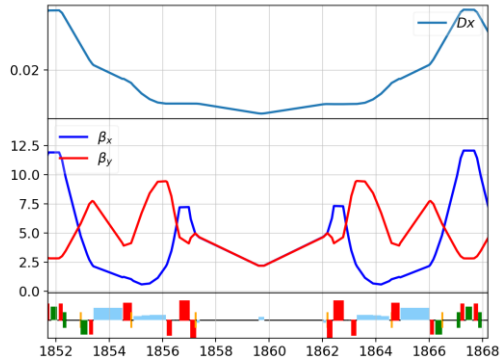
Local Momentum Accep.



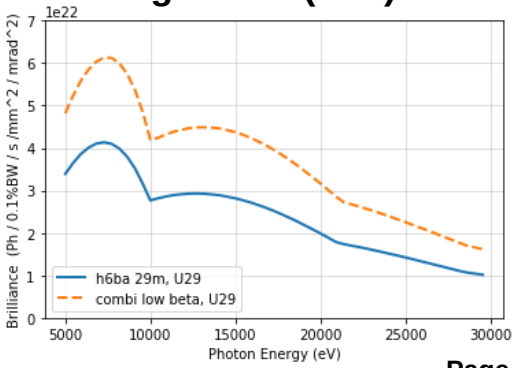
Lifetime



Canting possible



Brightness (U29)

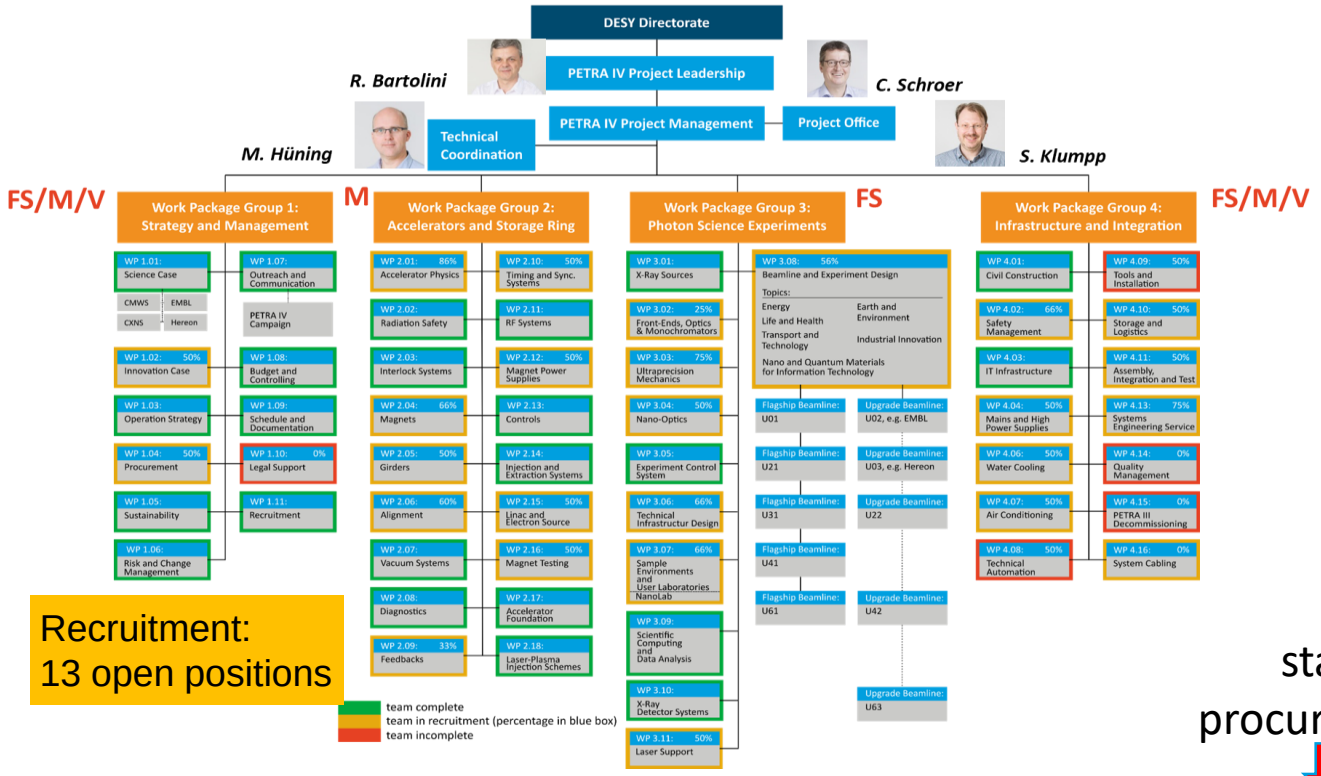


- Ease significantly injection chain → off-axis injection (low charge operation)
- Preserves most of undulator beamline Max v. Laue Halle
- Relaxes somewhat tolerance & allow for easier canting & increases lifetime

But … some work needs to be redone

Courtesy: I. Agapov

Organization in place / Revised timeline



Recruitment:
13 open positions

Old timeline has been recently revised
The draft breakdown below hinges on

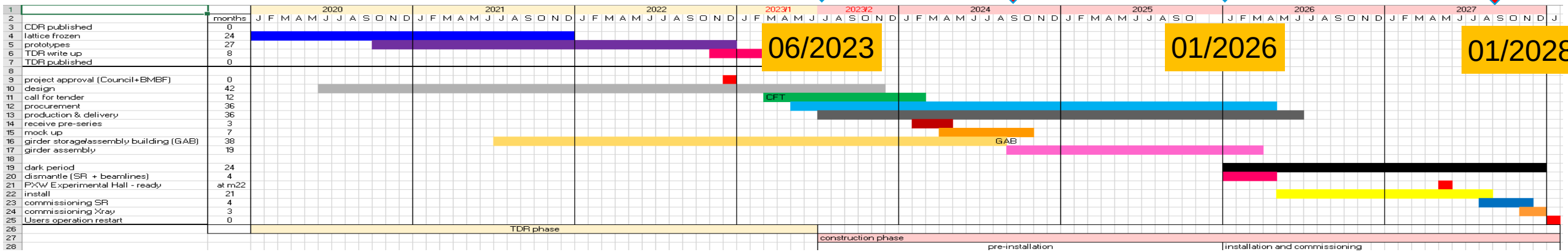
- Project approval in 2023
- Call for tender start mid 2023 (+6m)
- Dark period ~24 months
- Users' operation resumes in Jan 2028 (+1yr)

start procurement

girders assembly

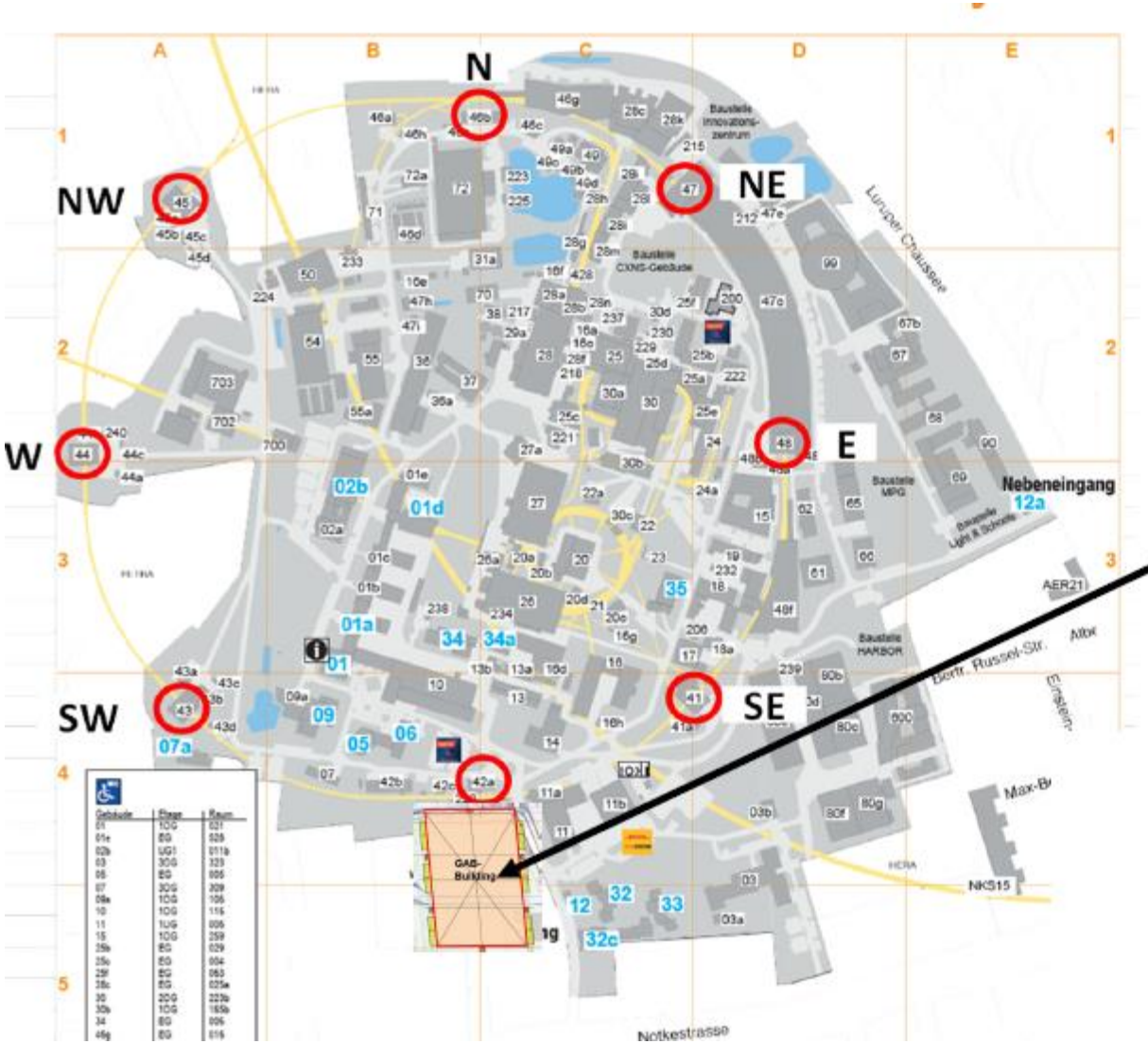
PIII shut down

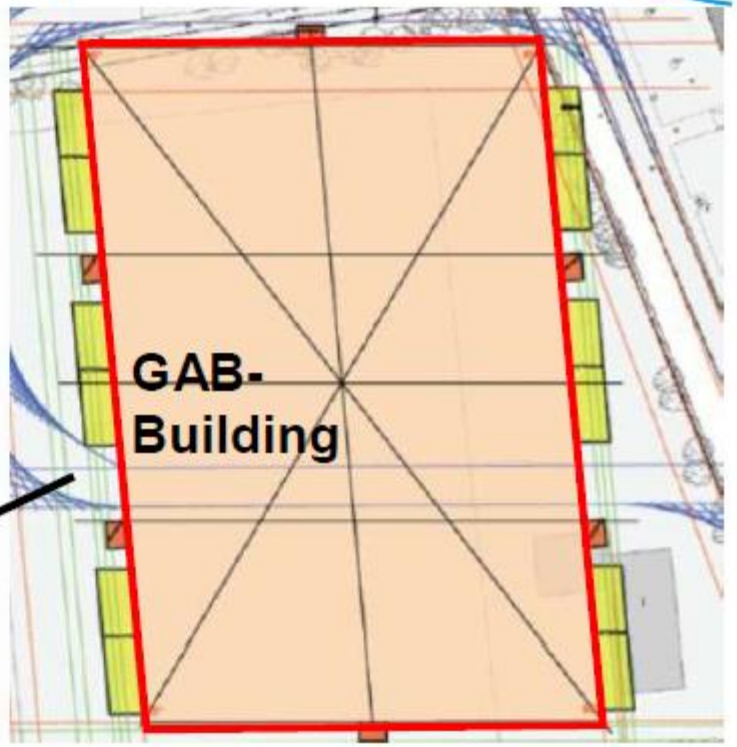
PIV ring commissioning



Girder assembly will be in a new building (GAB)

- Girder Assembly Building: **outside DESY campus** – simplified administrative procedures!



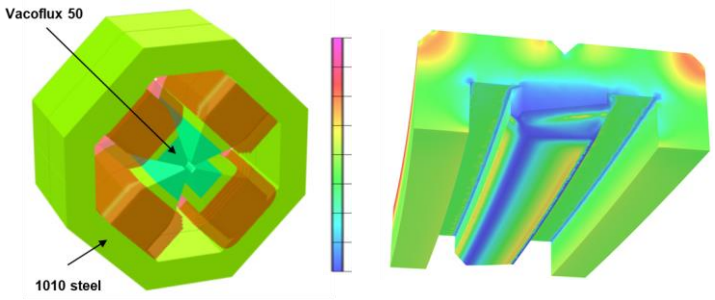


Simplification of the logistic plan

- Reemtsma Hall completely eliminated
- use of the HERA complex significantly reduced

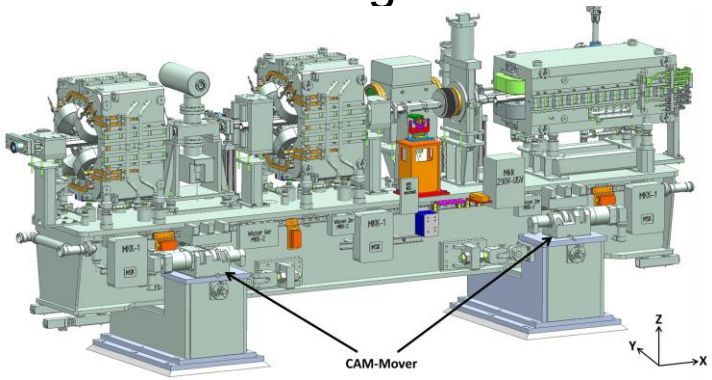
PETRA IV: system engineering challenges …

- Magnet designs



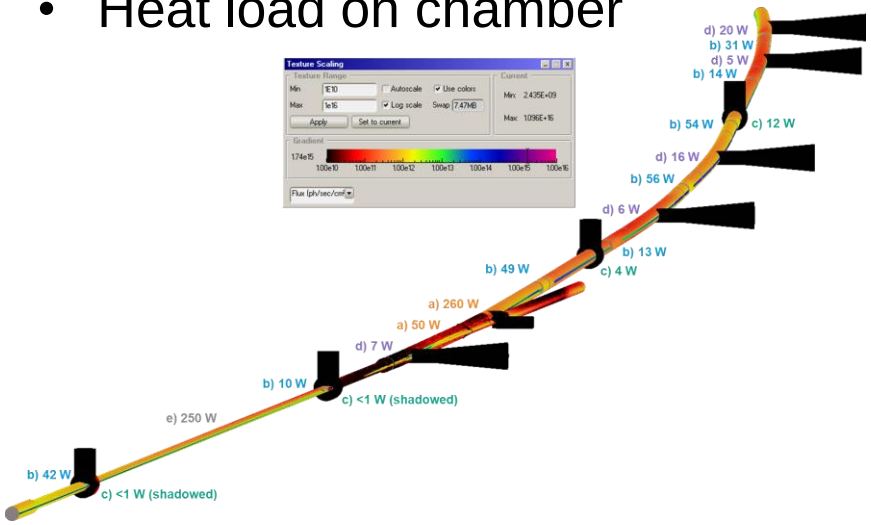
120T/m quad or combined fct magnets

- Girder design

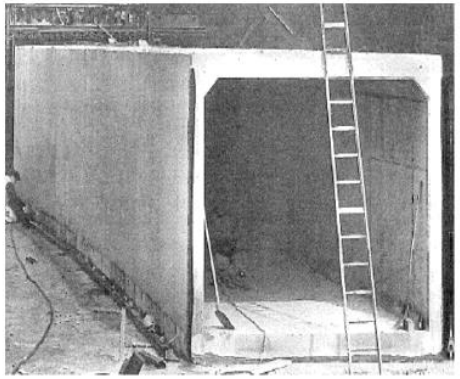


With high eigen frequencies

- Heat load on chamber

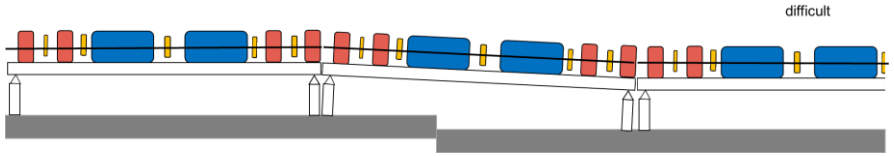


- Tunnel segmentation



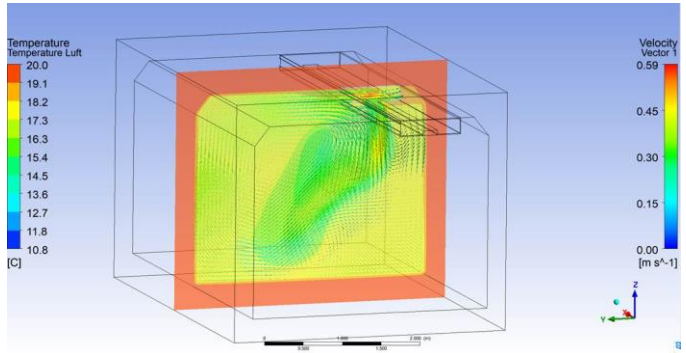
Old tunnel ~ 24m long segments

Biological inspired. Cast iron



How to deal with cracks / tunnel-exp hall

- Tunnel temp. stability (~0.1deg)



- … and many more e.g. 2000 magnets + PS, first turn, diagnostics, logistics, ….

Speed talk: MicroTCA HW develop. **M. Fenner**

Courtesy: Koldrack/Bieler/Agapov/Lilje/Aloev

FLASH = Free electron LASer at Hamburg

& FLASH2020+

FLASH – The Free-Electron Laser at DESY

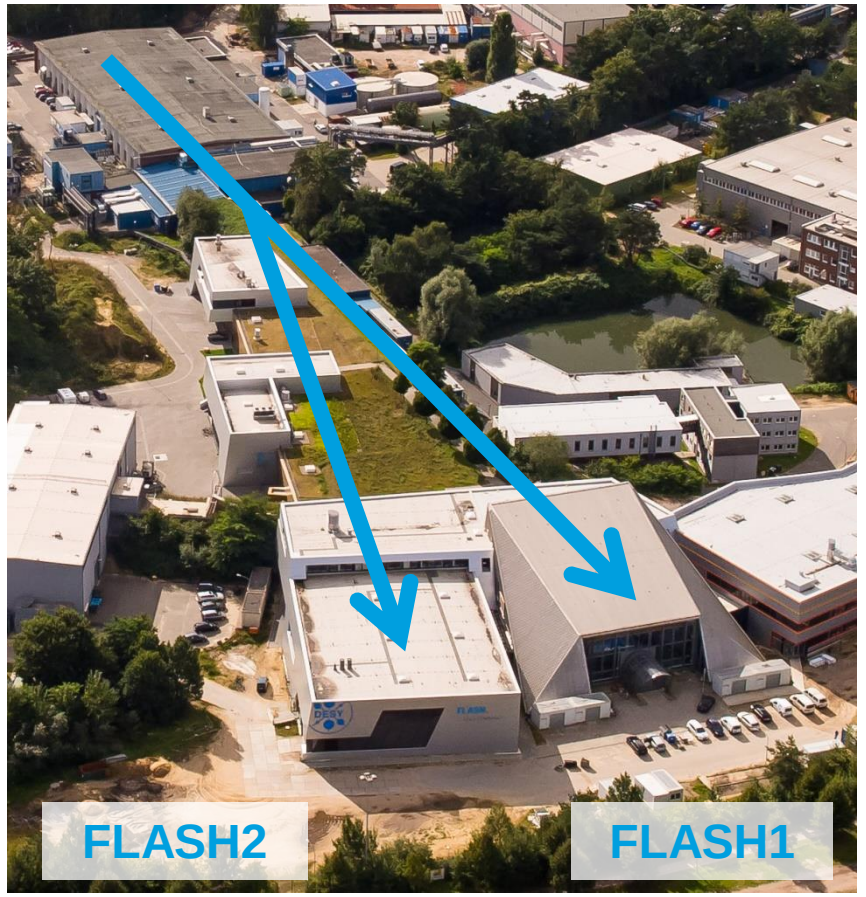
The first soft X-ray FEL operating two undulator beamlines simultaneously

FLASH is a user facility

- 2005 - Start user operation
- 2014 - Two undulator beamlines operated simultaneously
- 7500 hours of linac beam operation (60% user / 30% studies / 10% ARD)

FLASH accelerator

- … is a single-pass high-gain SASE FEL (300 m long)
- … is based on a superconducting accelerator
  - 1.25 GeV using TESLA/XFEL technology
  - allowing several thousand bunches per second
- … with transversely coherent femtosecond scale photon pulses
- … in the wavelength range from XUV to soft X-rays (90 nm to 4 nm)
- with an integrated powerful THz source



FLASH includes an accelerating R&D program

- ➢ Xseed (External seeding development) ARD-ST3
- ➢ FLASHForward (Plasma wakefield experiment) ARD-ST4

Courtesy: S. Schreiber et al.

FLASH Layout

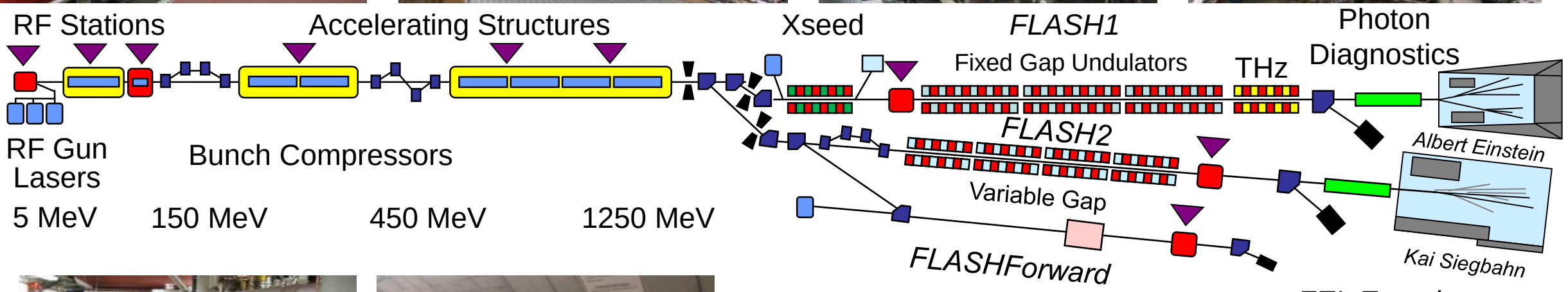
Courtesy: S. Schreiber et al.

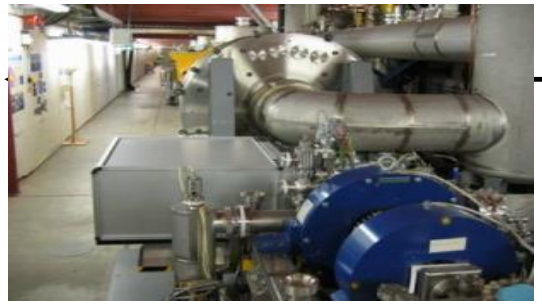
3rd harmonic sc module 3.9 GHz

TESLA type superconducting accelerating modules 1.3 GHz

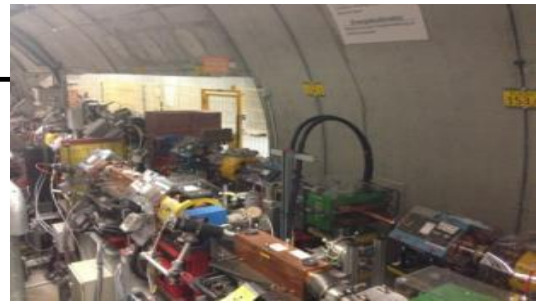
FLASH1 fixed gap undulators

FLASH1 Albert Einstein Hall





Normal conducting 1.3 GHz RF gun
Ce_2Te cathode / 3 injector lasers



Extraction to FLASH2

FLASH2 variable gap undulators

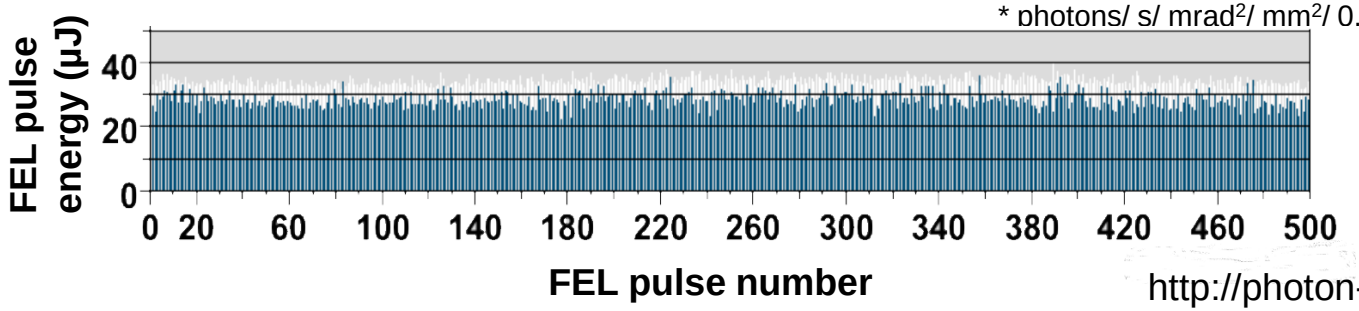
FLASH2 Kai Siegbahn Hall

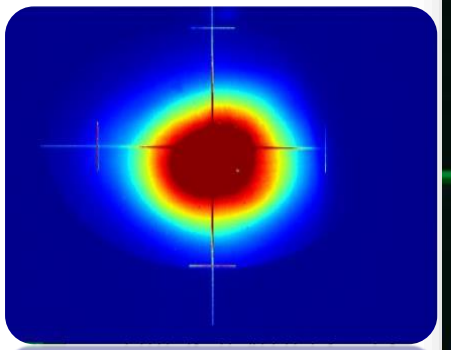
FLASH Parameters delivered to users

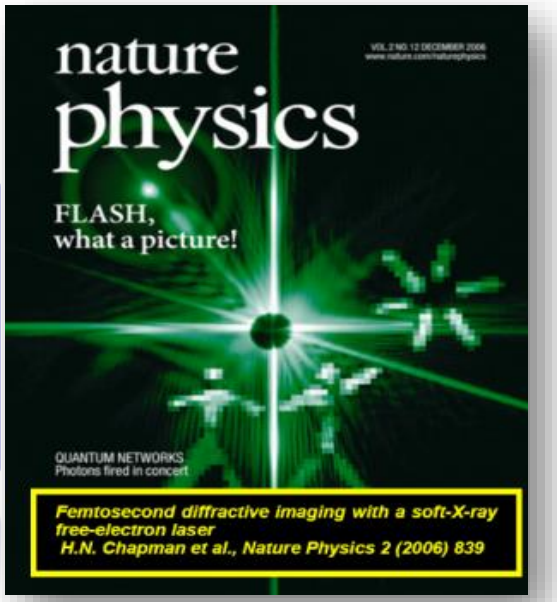
Machine and FEL parameters

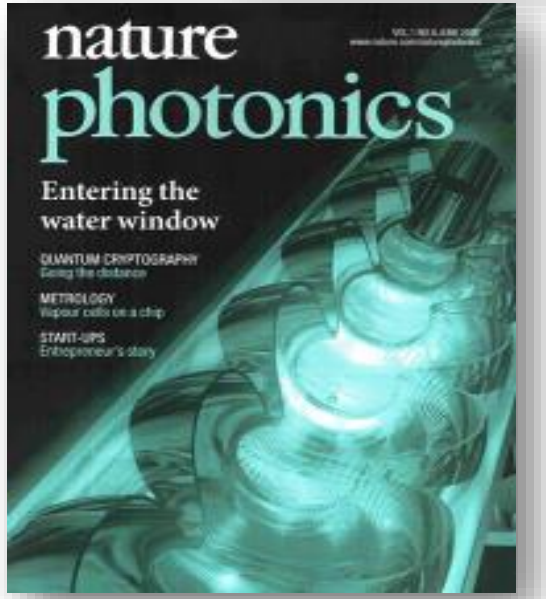
FEL Radiation Parameter FLASH1 / FLASH2	
Beam energy	up 1.25 GeV
Undulator gap	fixed / variable
Wavelength range (fundamental)	4.2 – 51 nm / 4 – 90 nm
Undulator period	27.3 mm / 31.4 mm
Average single pulse energy	1 – 500 µJ / 1 – 1000 µJ
Pulse duration (FWHM)	< 30 – 200 fs
Peak power (from av.)	1 – 5 GW
Pulses per second	10 – 5000
Spectral width (FWHM)	0.7 – 2 % / 0.5 – 2 %
Photons per pulse	10^{11} – 10^{14}
Average Brilliance	10^{17} – 10^{21} B*
Peak Brilliance	10^{28} – 10^{31} B*

* photons/ s/ mrad^2/ mm^2/ 0.1%bw









http://photon-science.desy.de/facilities/flash/publications/scientific_publications

Courtesy: S. Schreiber et al.

SASE performance

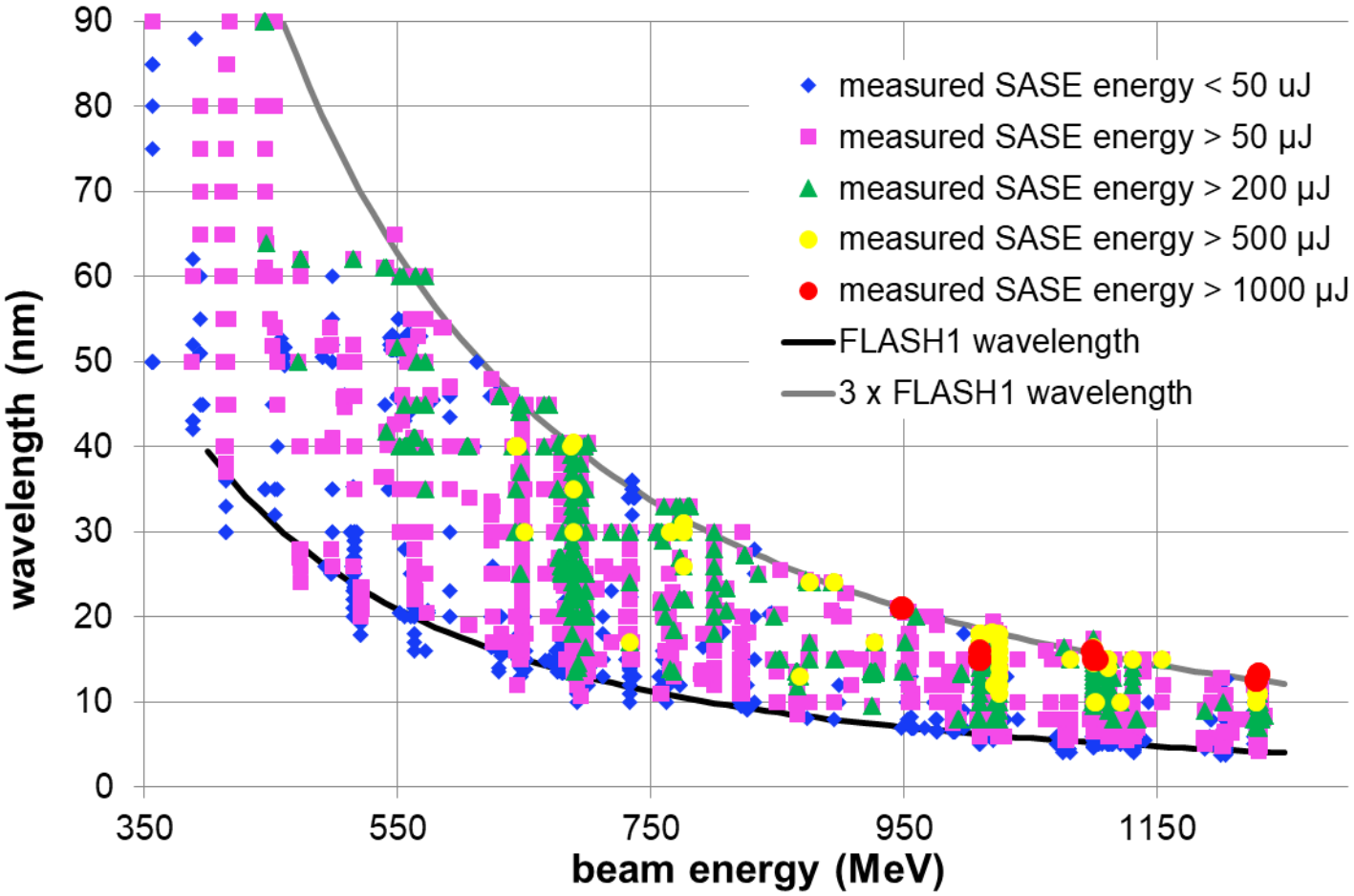
One accelerator, two undulator beamlines

Wavelength

FLASH1: fixed gap undulators
- Wavelength is beam energy dependent
- Energy change of more than 20 MeV requires a new FLASH2 setup

FLASH2: variable gap undulators
- Wavelength range = $[\lambda_{FLASH1}; 3 \cdot \lambda_{FLASH1}]$

- Variable gap undulators in FLASH1 is a major goal of FLASH2020+



Courtesy: S. Schreiber et al.

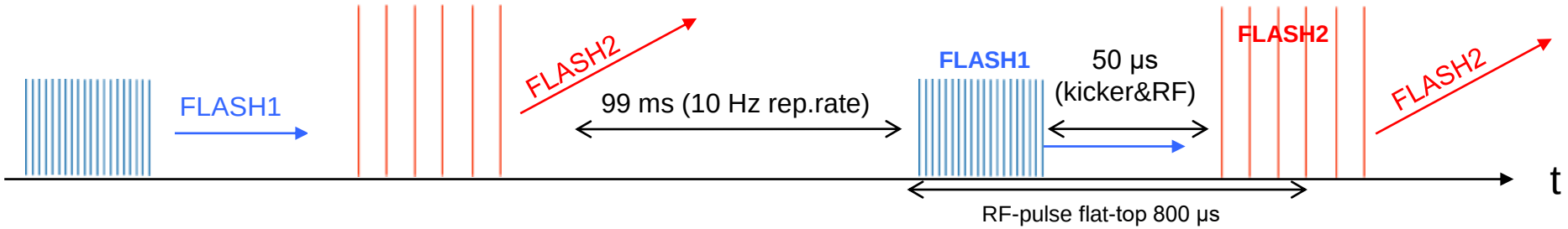
Realization of Simultaneous Operation

Large flexibility in beam parameters

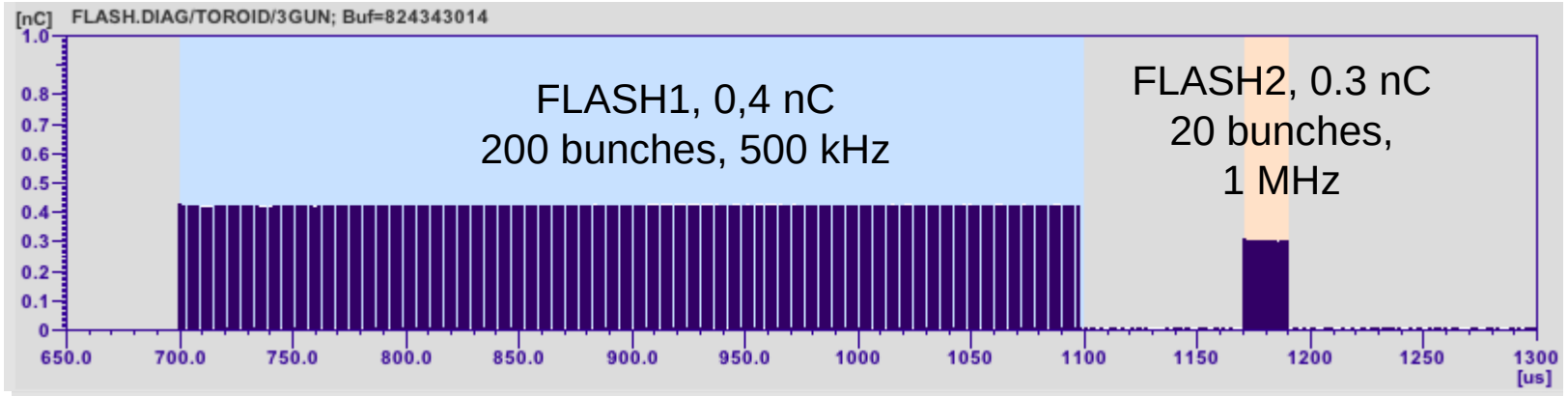
Speed talk: Micro Bunching by **P. Amstutz**

Speed talk: Fast charge by **J. Kral**

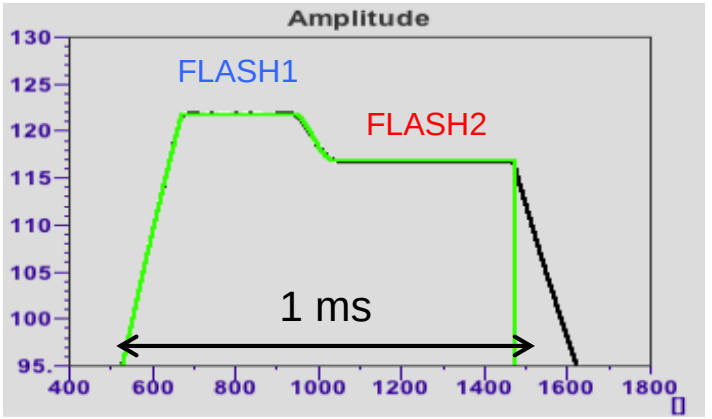
- Fast kicker and Lambertson septum to extract part of the bunch train to FLASH2



- Three injector lasers: Bunch charge and bunch pattern are selected independently for FLASH1 and FLASH2
- Flexible RF-system: amplitudes and phases are adjusted - within certain limits - independently for FLASH1 and FLASH2
  → flexible bunch compression, flexible in photon wavelength and energy



RF-pulse amplitude



Courtesy: S. Schreiber et al.

FLASH2020+

FLASH2020+ plans for a new coherent source at DESY

E. Allaria, N. Baboi, K. Baev, M. Beye, G. Brenner, F. Christie, C. Gerth, I. Hartl, K. Honkavaara, B. Manschwetus, J. Mueller-Dieckmann, R. Pan, E. Plönjes-Palm, O. Rasmussen, J. Roensch-Schulenburg, L. Schaper, E. Schneidmiller, S. Schreiber, K. Tiedtke, M. Tischer, S. Toleikis, R. Treusch, M. Vogt, L. Winkelmann, M. Yurkov, J. Zemella

on behalf of the FLASH2020+ team

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Survey scientific demands for Free Electron Lasers

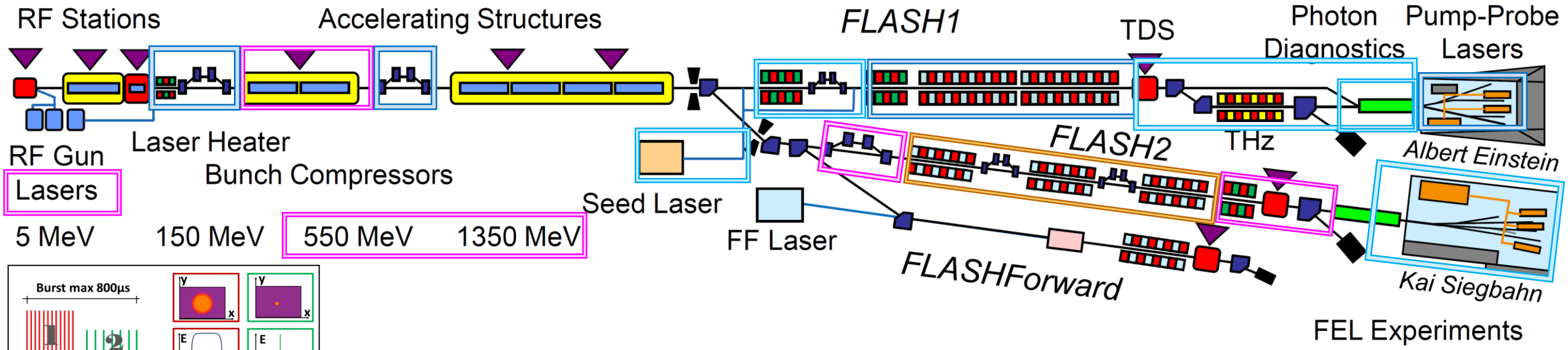
Discussion with FLASH and soft X-ray user community defined new wishes for FLASH

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 for **multi-color 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 (100 kHz)	Low hit rate experiments	*Postponed as long-term goal (2030+)*	

Courtesy: E. Allaria

FLASH2020+ four phases

An upgrade plan of the full facility has started for extending FLASH capabilities



Courtesy: E. Allaria

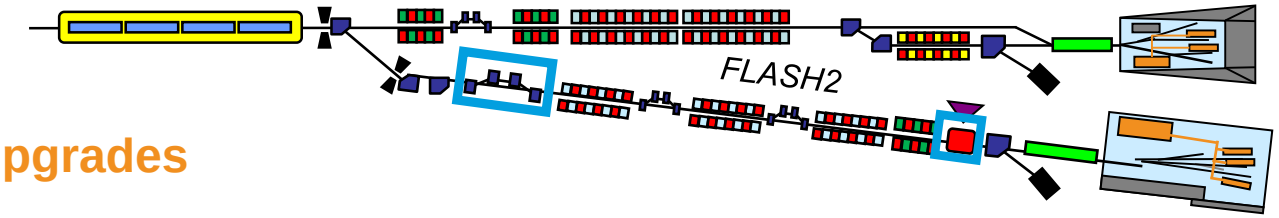
Phase 0
Injector Laser
Energy upgrade
3rd BC (FLASH2)
Afterburner FLASH2
TDS (FLASH2)

Phase 1
Laser heater in 1st BC
New 2nd bunch compressor (BC)
Variable gap undulators (FLASH1)
Pump-probe laser (FLASH1)

Phase 1+
High rep.rate seeding (FLASH1)
Photon diagnostics (FLASH1)
Flexible pump-probe
New beamlines

Phase 2
New variable gap undulators
Chicanes for new lasing concepts (FLASH2)

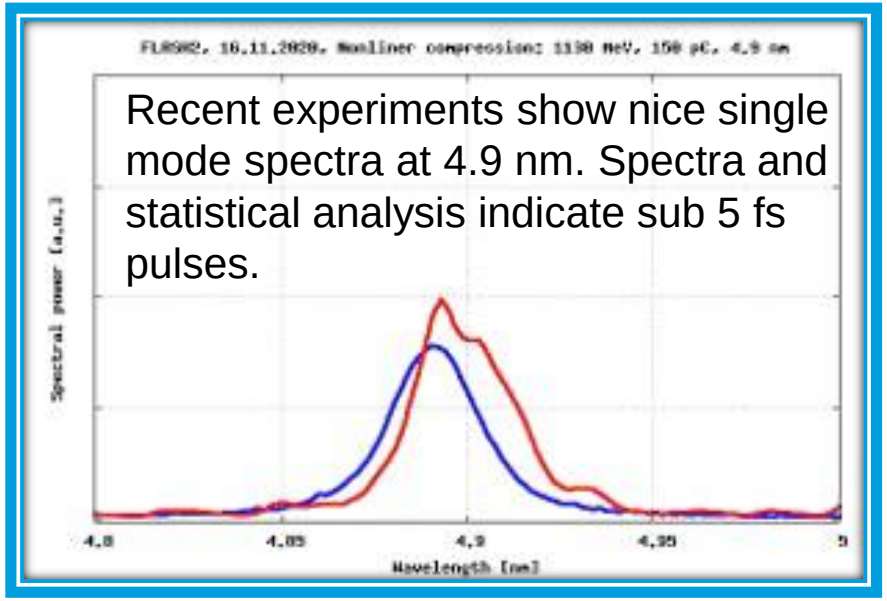
Already completed upgrades

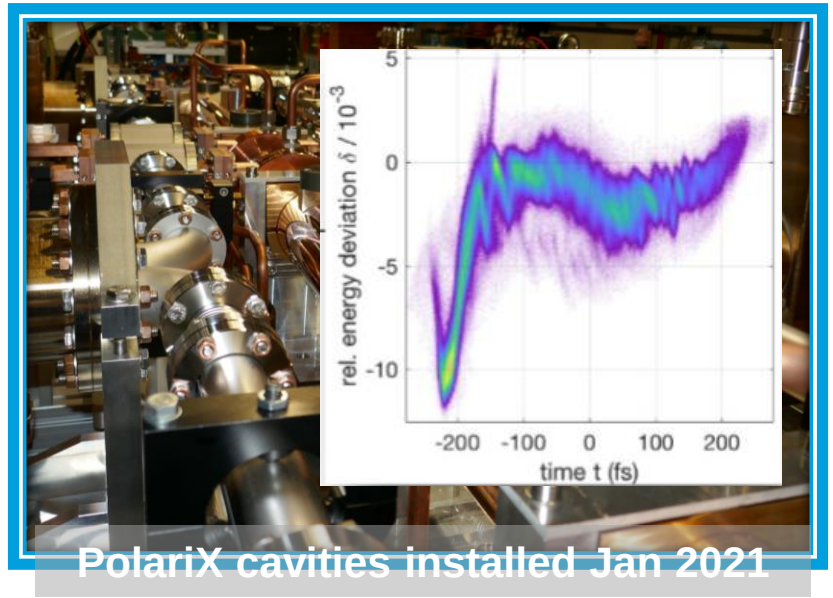


Improved FLASH2 operations thanks to completed upgrades

New **FLASH2 bunch compressor**:

- easy and stable FEL operation at short wavelength (>50μJ measured at λ~4nm);
- Additional options for FLASH2 (single-spike operation at λ~4 nm now also possible nonlinear compression).





New **PolariX TDS** for:

- further optimization of e-beam;
- online monitor of FEL pulse length.

Progressing with the new **FL23 beamline** with time-delay compensation monochromator optimized for:

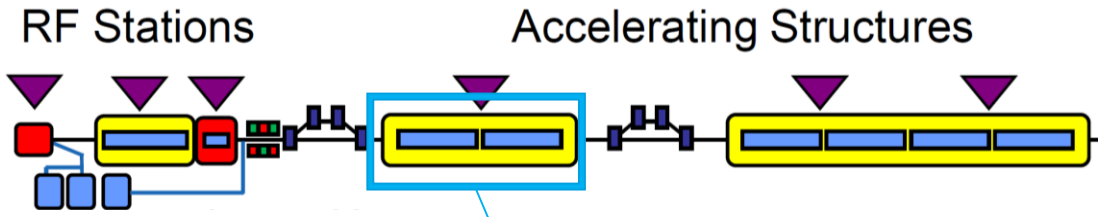
- Short wavelength (2 – 20 nm)
- Short pulses (50 fs);

Courtesy: E. Allaria

Energy upgrade

From 2022 energy increased to 1.35 GeV

The new modules will allow an energy increase of **100 MeV** from 1.25 GeV to 1.35 GeV
➔ tuning range of FLASH2 **beyond 4nm**

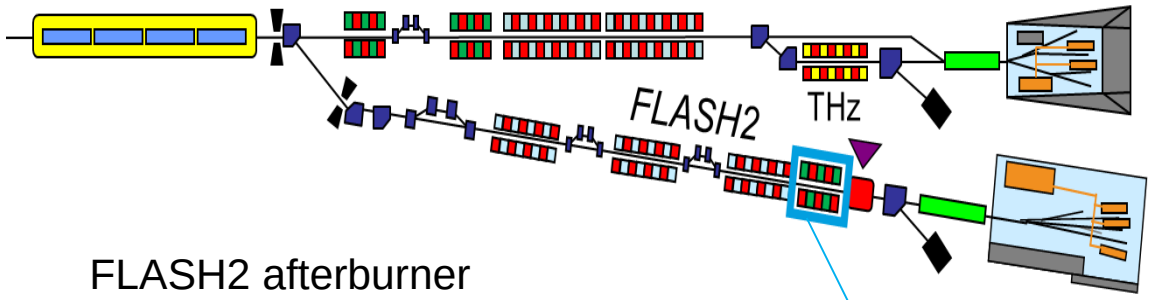


Courtesy: E. Allaria

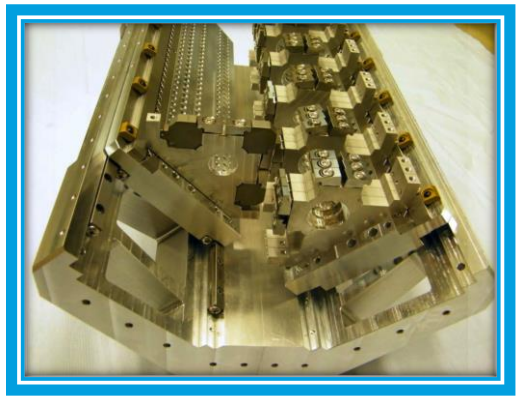
New undulators

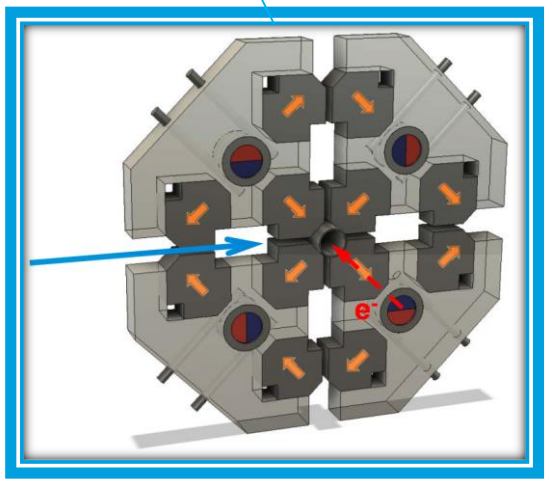
APPLE III for variable gap variable polarization

Extension of tuning range to shorter wavelength down **to 2 nm** with the after burner undulator in FLASH2.
➔ Pulses with **few μJ** in **circular polarization**



FLASH2 afterburner
λ_u = 16 mm
gap ≥ 8 mm



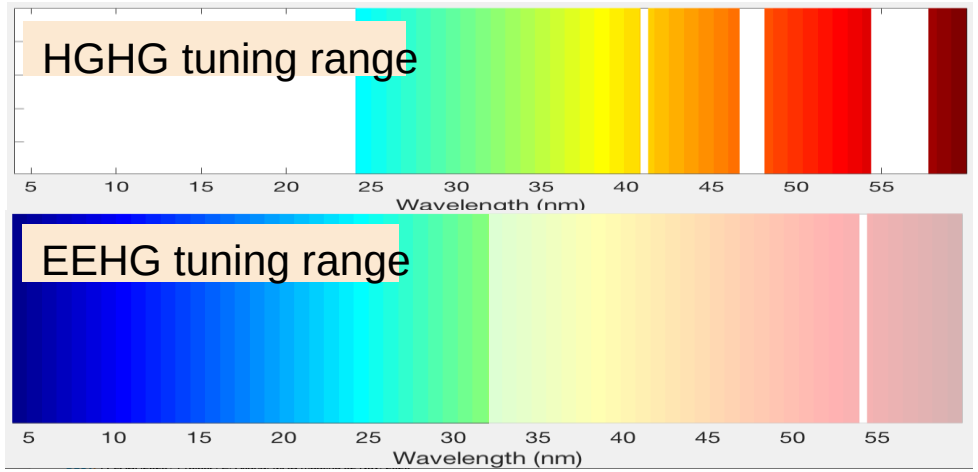


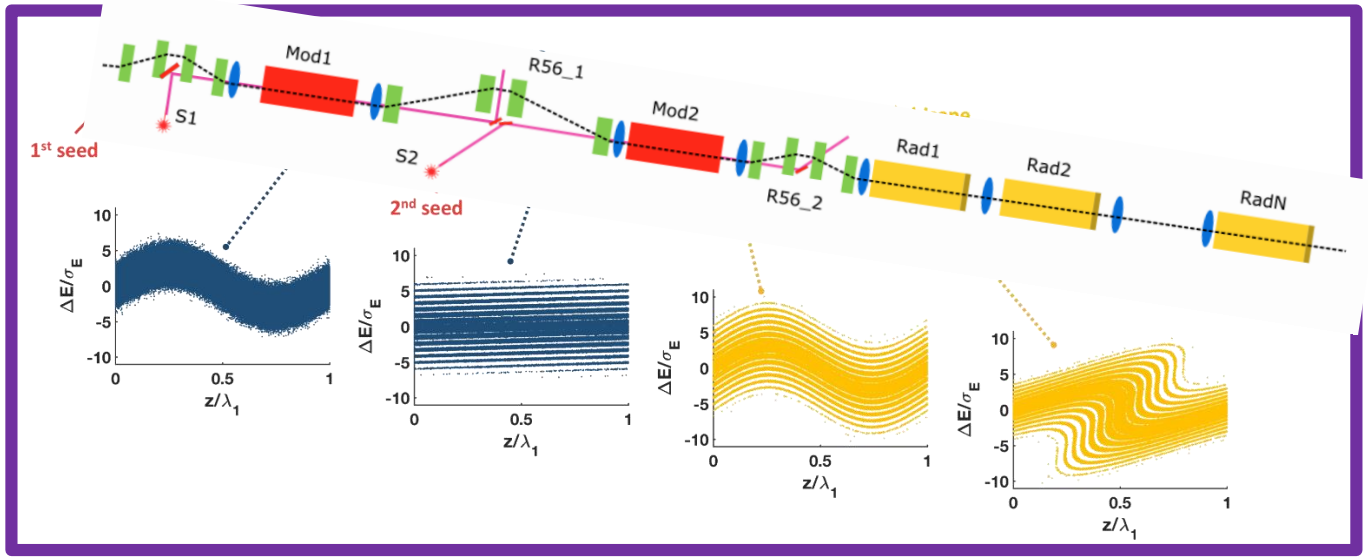
FLASH2020+ seeding in FLASH1

Starting from 2025 100 kHz – 1 MHz coherent pulses in soft-X-ray

Courtesy: E. Allaria

Reaching **4 nm** seeding with UV seed lasers is possible with Echo Enabled Harmonic Generation (EEHG).





Fully coherent pulses as short as **10 fs** with variable polarization in the range **60 – 4 nm** at **high repetition** rate.

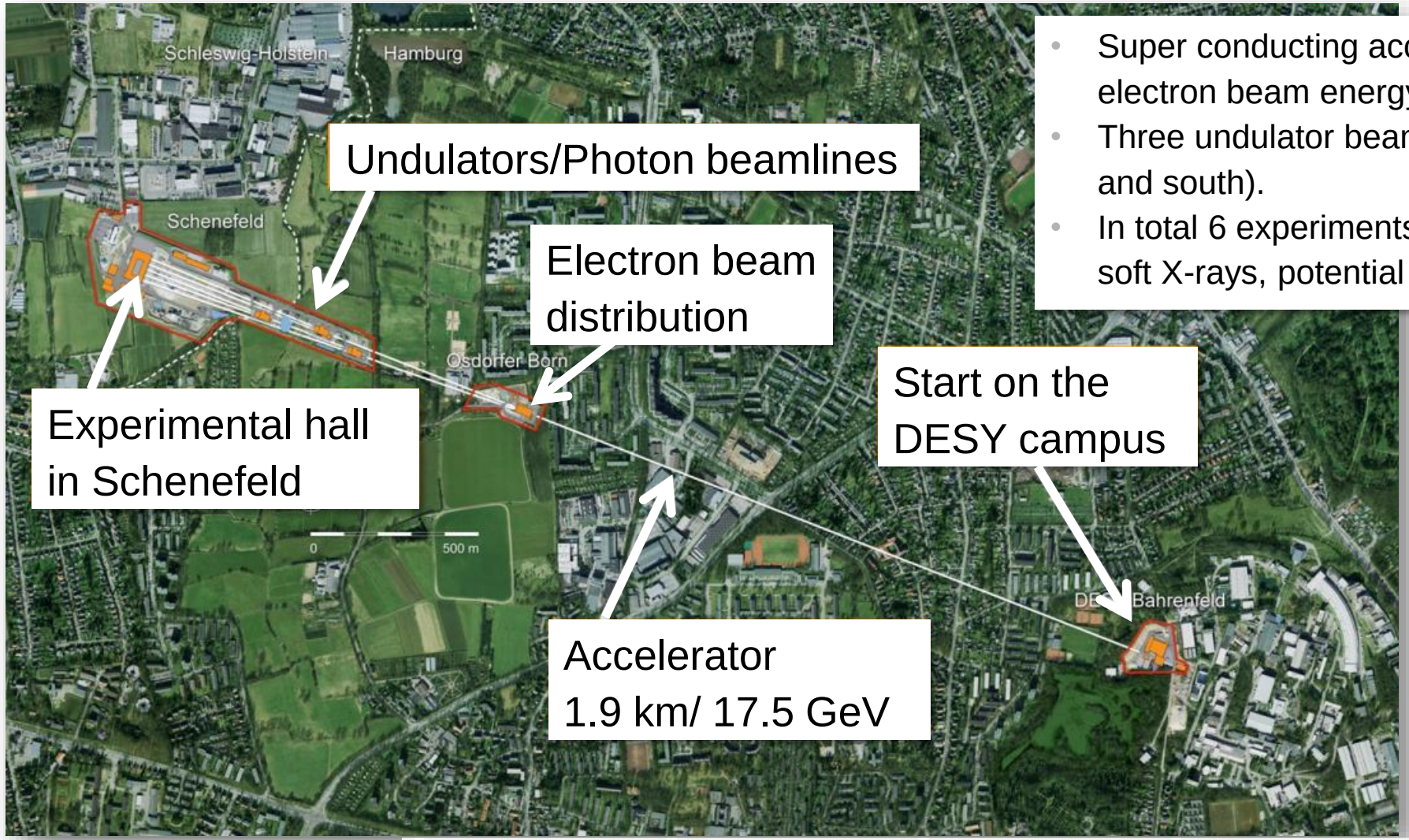
Parameter	Seed1	Seed2	units
Wavelength	343	297 – 317	nm
Peak power	100	300	MW
Pulse length	>200	50	fs
Bandwidth	Not critical	Fourier limited	
Pulses per second	10 - 5000	10 - 5000	

Courtesy: E. Allaria

Talk: Seeding challenges by **Pardis Niknejadi**

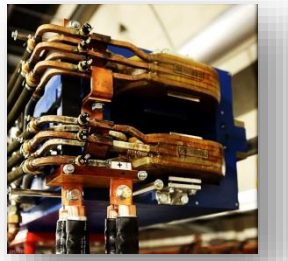
European XFEL

The European XFEL between Hamburg Bahrenfeld and Schenefeld



- Super conducting accelerator with up to 17.5 GeV electron beam energy.
- Three undulator beamlines in two branches (north and south).
- In total 6 experiments, 4 for hard X-rays and 2 for soft X-rays, potential for 2 more FELs

Schematic accelerator overview

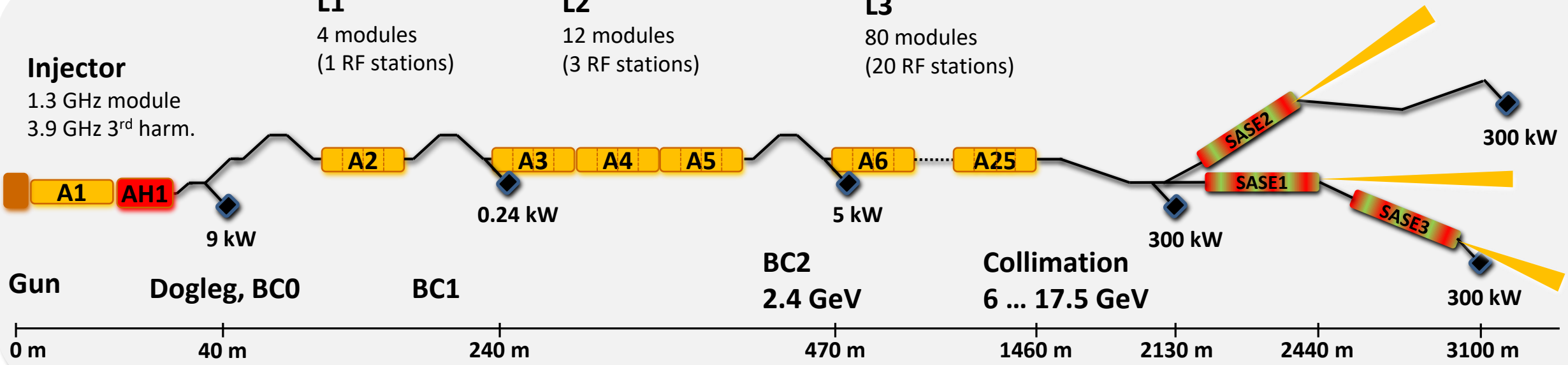


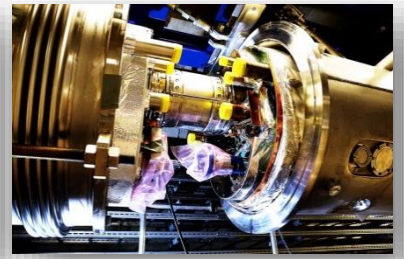
Injector
1.3 GHz module
3.9 GHz 3rd harm.

L1
4 modules
(1 RF stations)

L2
12 modules
(3 RF stations)

L3
80 modules
(20 RF stations)



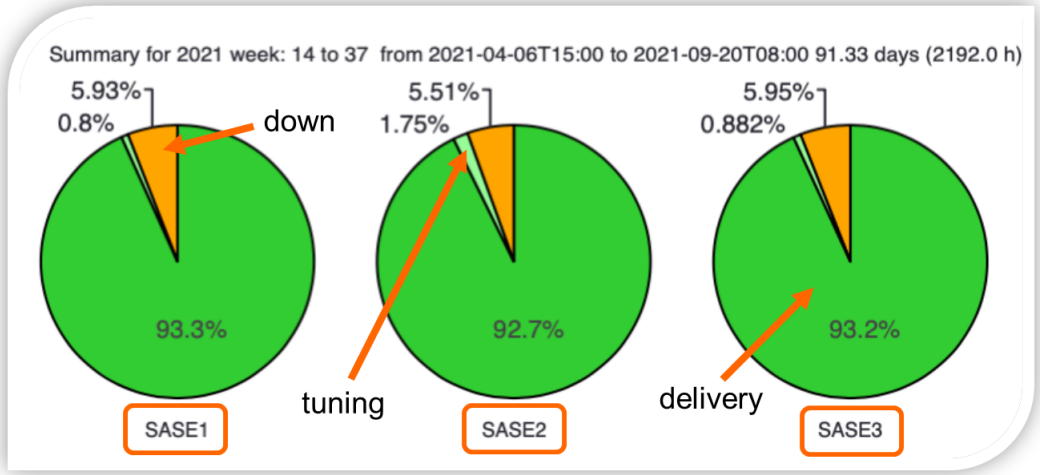




- EuXFEL performed most of the time very well during the last six months.
- This plot shows the pulse energies in all beamlines over a time period of 5 hours.
  - The signals are very stable over time and all in the mJ-range.
  - No interuptions
  - Homogeneous pulse intensities over the pulse trains (here SASE1 and SASE3).

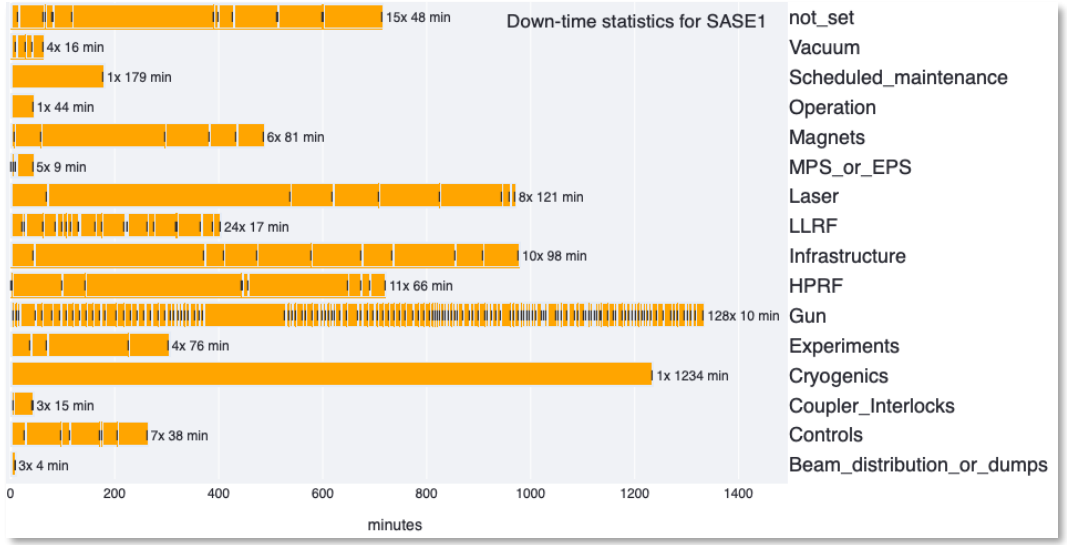
Courtesy: M. Scholz

Focus work on improvements for availability…

Availability statistics

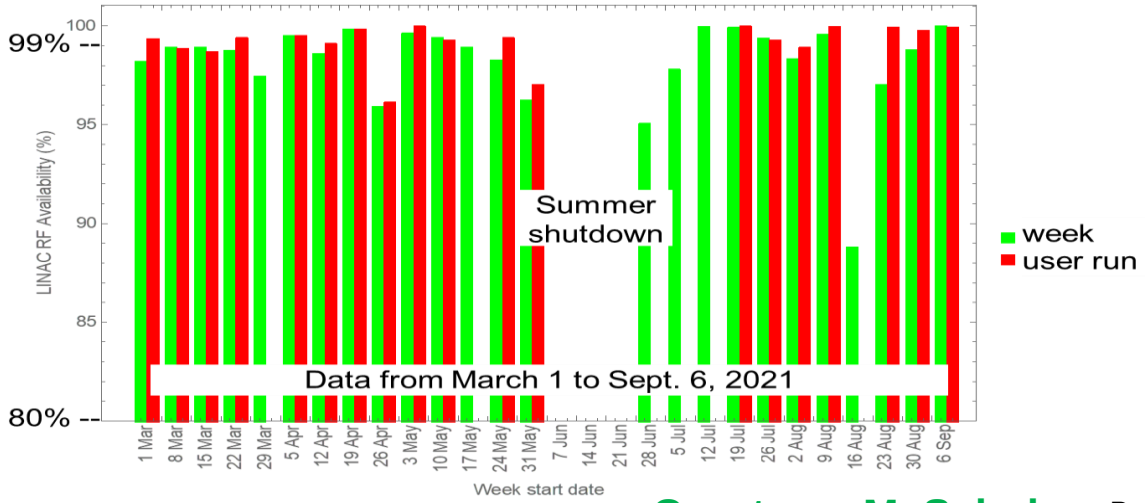


Fault statistics



SASE Performance

SRF linac availability

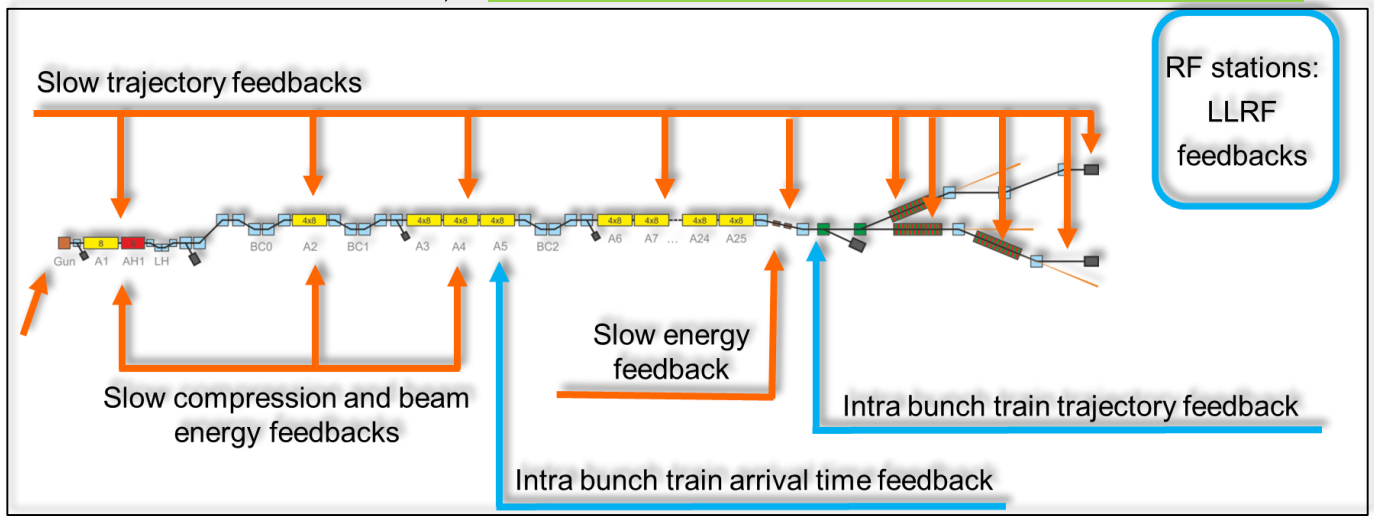


Courtesy: M. Scholz

… stability & reproducibility & capabilities…

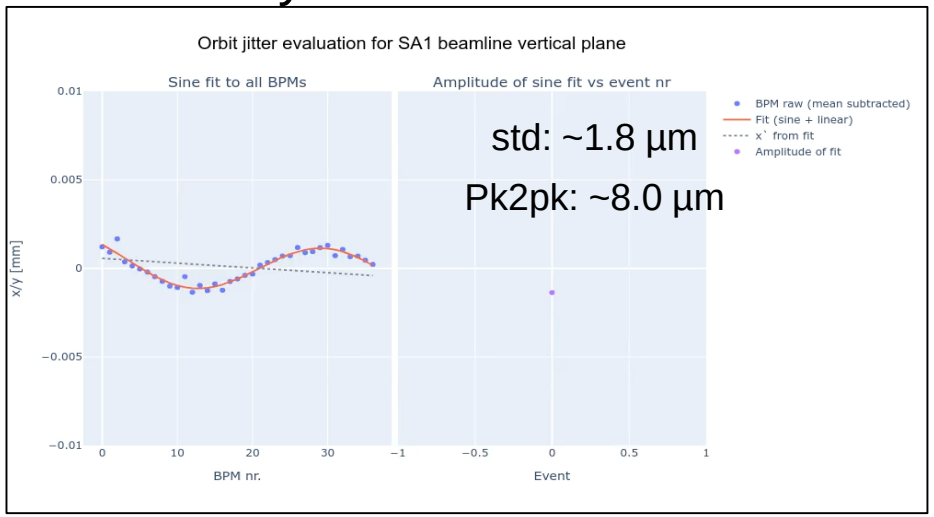
Feedbacks

Speed talk: fs arrive FB by **B. Lautenschlager**



Orbit stability

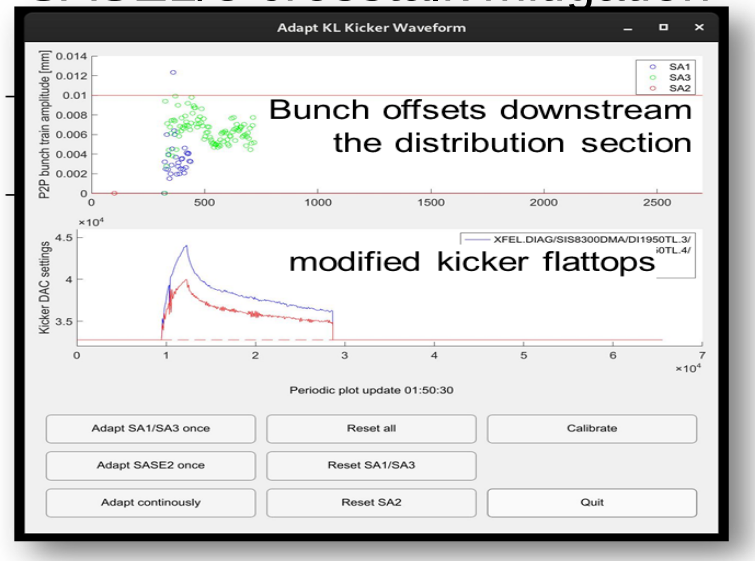
Courtesy: M. Scholz



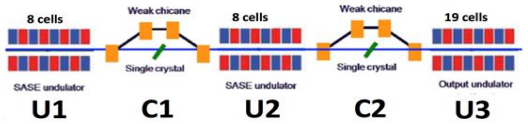
SASE1/3 crosstalk mitigation

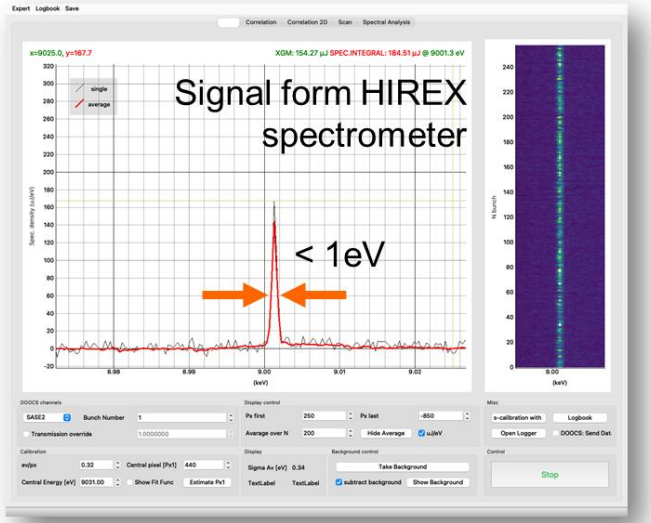
10 um

0 um



Hard X-ray self seeding HXRSS

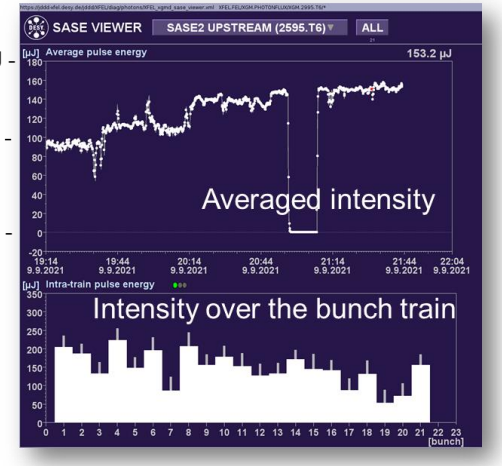




180 uJ -

100 uJ -

0 uJ -

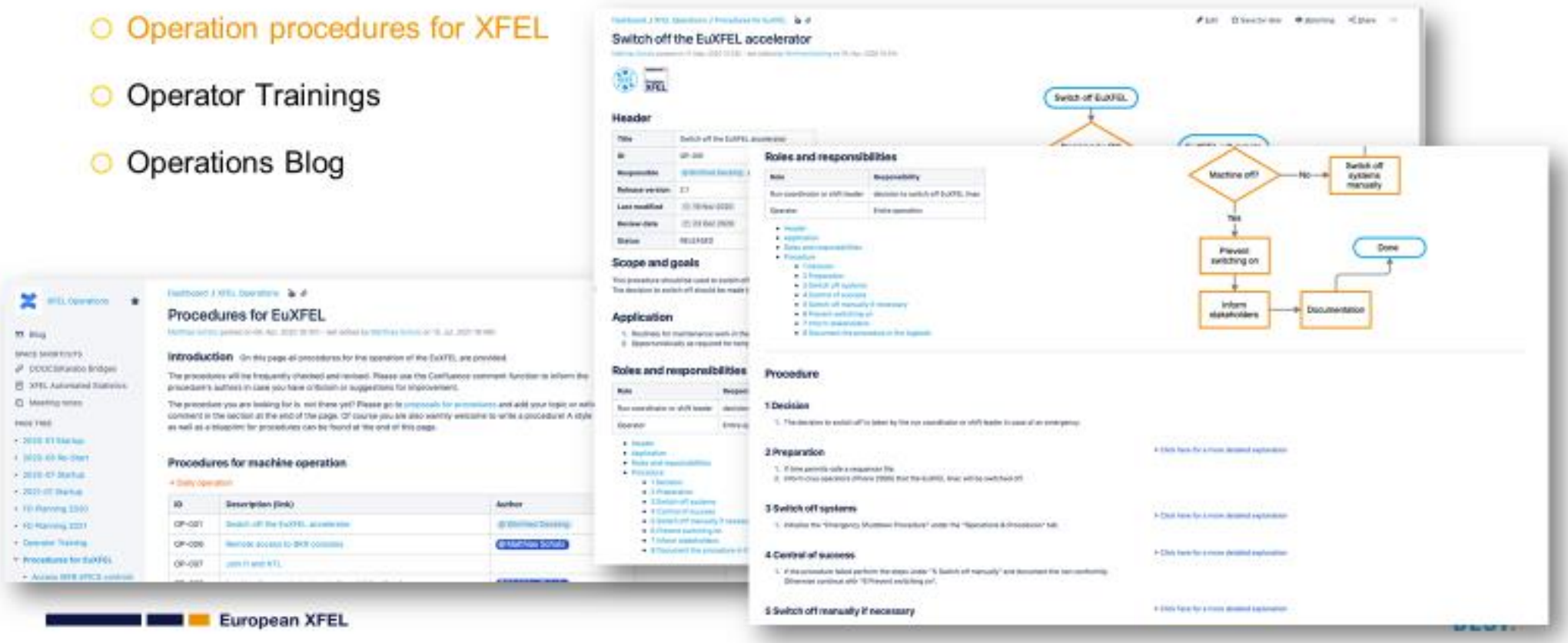


… and work on further automation & tuning mechanism

Operation: Standardisation and Automation

Courtesy: M. Scholz

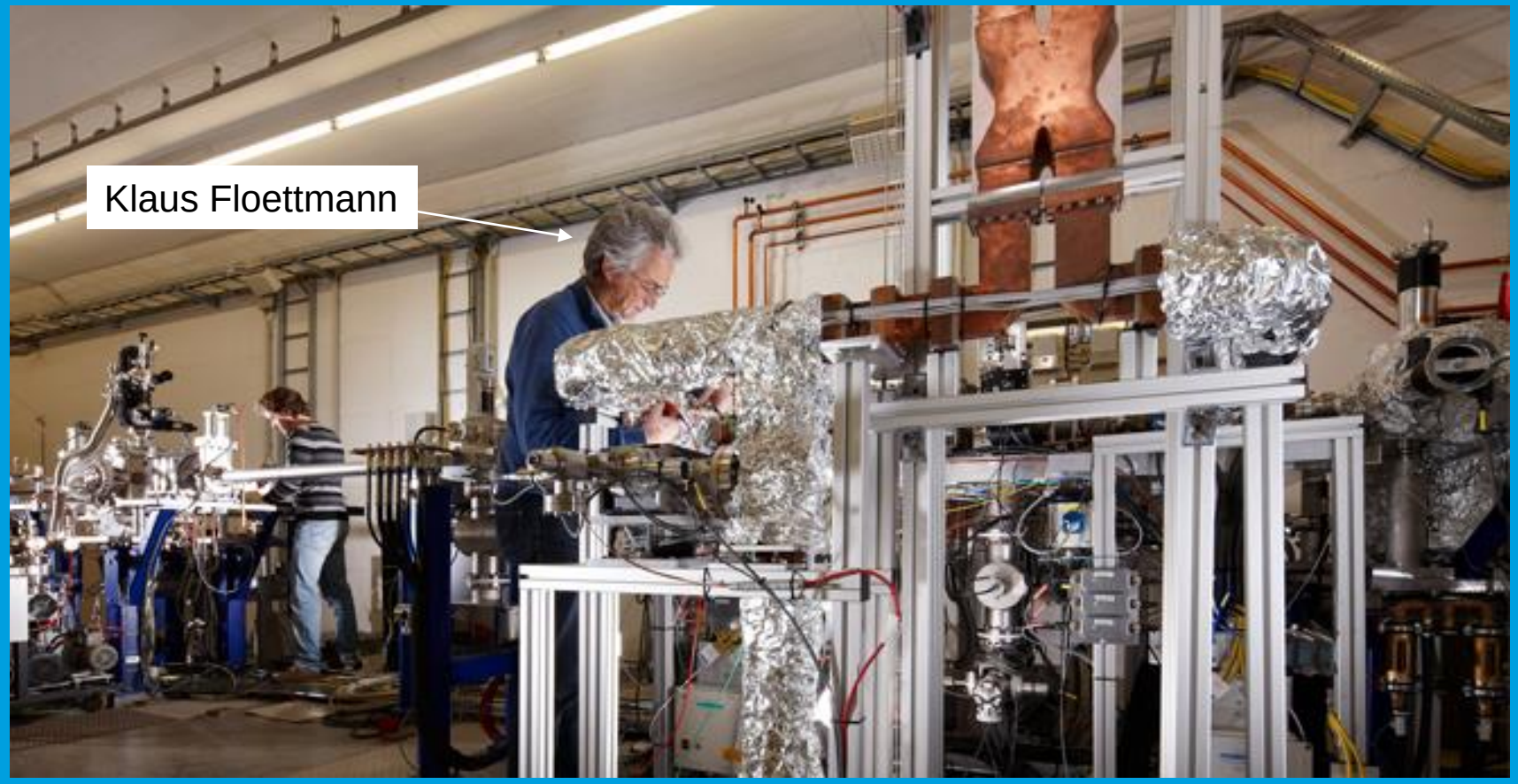
- To enable as many operators as possible to run XFEL at the same performance as the experts, the following supports are available:
  - Operation procedures for XFEL
  - Operator Trainings
  - Operations Blog



Speed talk: Decentralize FB opt. Synchr **M. Schuette**

Speed talk: Long phase space prediction **J. Zhu**

REGAE = Relativistic Electron Gun for Atomic Exploration

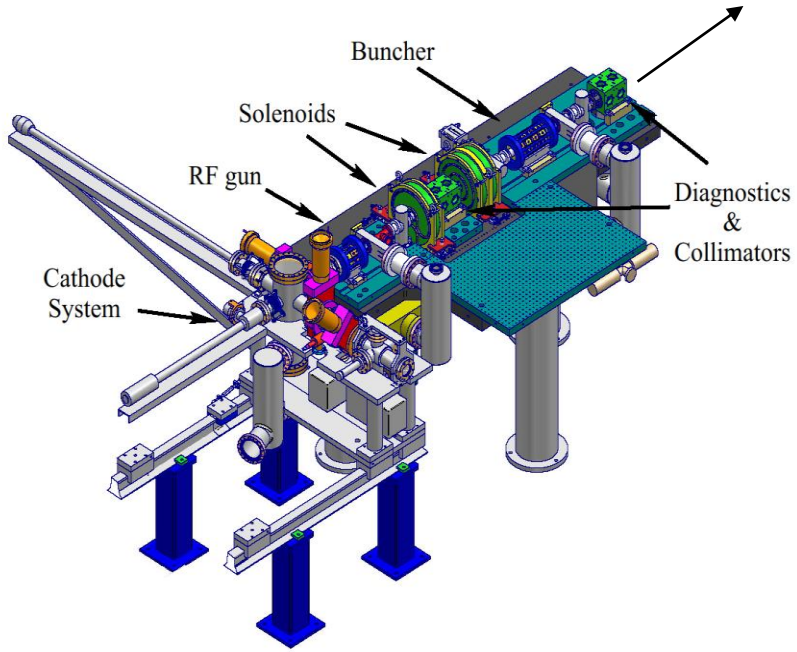


Science case for REGAE

High-resolution time-resolved structural investigations of ultrathin low-Z samples.

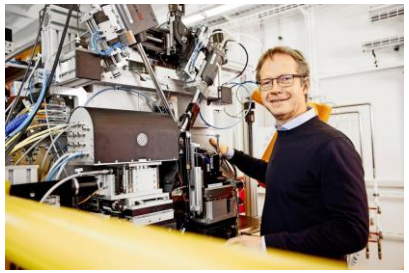
REGAE´s electron beam parameters:

- Energy: 2.5 - 5 MeV
- Bunch charge: 100 fC
- Pulse duration: > 20 fs
- Beam size at sample position: 500 x 500 um^2
- Coherence lengths: ~ 1 nm (rms)
- Repetition rate: 12.5 Hz (in future: 100 Hz)



General advantage of 3 MeV electrons over X-rays

- ~10^5 x **larger elastic cross** section
- Radiation **damage reduced** by ~ 1000 times
- Better **visibility of hydrogen atoms**
- Photon equivalent of 100 fC electron pulse are about 10^{11} photons at 12 keV



PI: Alke Meents

-> ideally suited for structural investigations of **ultrathin low-Z materials**

Challenges with electron diffraction

- Bunch charge effects preventing microbeam experiments
- Sample thickness limited to < 1 µm
- Experiments require ultra high vacuum (UHV)
- Sample preparation and delivery is most challenging, in particular for liquids and hydrated biological samples

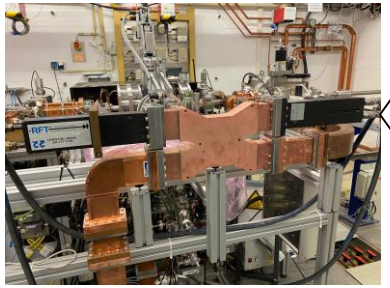
https://regae.desy.de/

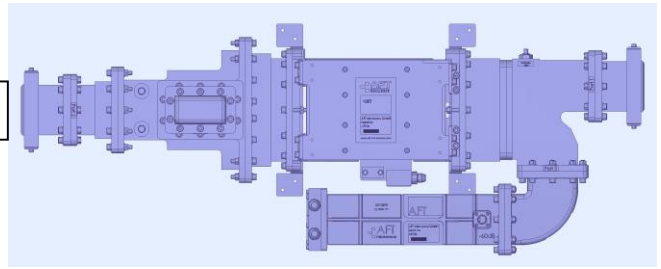
Courtesy: Alke Meents/Klaus Floettmann

Current challenges

Technical improvements to guarantee stable and reliable operation

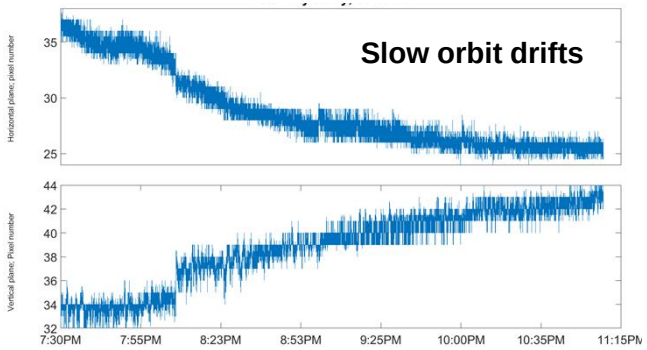
- Circulator to decouple klystron from gun/buncher cavity.



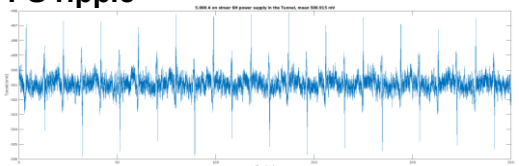


circulator from AFT, operated with dry air at 3 atm

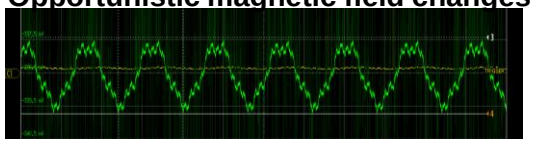
- Improvement of vacuum system & controls
- Overpower protection for sensitive equipment
- Improved environmental controls
  ➔ magnetic field /EMI , temp, humidity, …



PS ripple

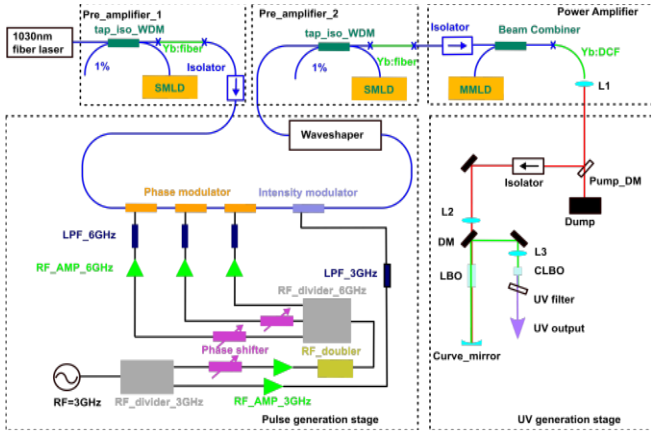


Opportunistic magnetic field changes

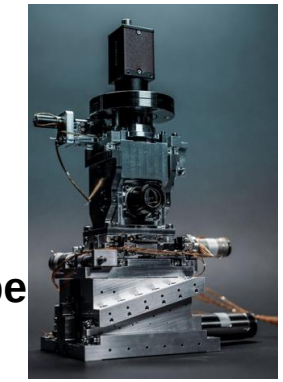


Upgrades done / planned…

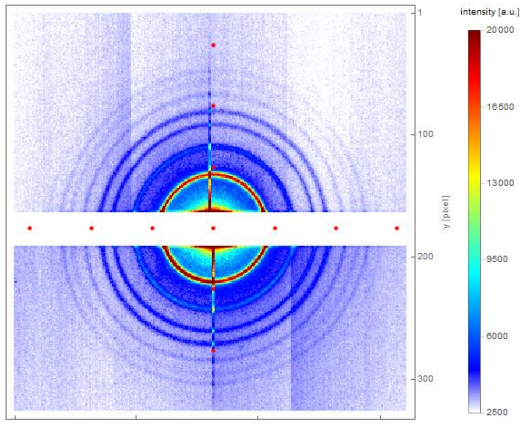
➢ **Coherent micro-beam mode with 3 GHz laser**
➔ Micrometer size electron beam



➢ **Inline sample viewing microscope**

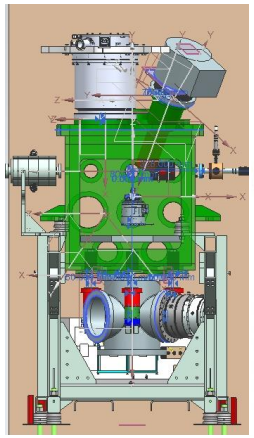


➢ **Jungfrau 1M detector**



Power diffraction 5nm TiO_2

➢ **High precision goniometer**



Courtesy: Alke Meents/Klaus Floettmann

ARES

THE ARES ACCELERATOR @ DESY

Accelerator R&D across subtopics in operation

Facility for **Accelerator R&D** & **novel acceleration techniques** testbed (DLA) & FLASH radiation therapy.

Regular user beam time (ACHIP collaboration & Helmholtz autonomous accelerator project).

Installation of bunch compressor and PolariX Xband TDS finished – needed for the production and characterization of **ultra-short pulses** (part of ATHENAe) → Commissioning ongoing.

Target parameters / commissioning parameters	
50 – 155 MeV	50 – 156 MeV
0.5 – 200 pC	0.1 – 100 pC
Single pulse @ 50 Hz	10 Hz
few fs / sub-fs pulse length	85 fs (w/o magnetic bunch compression)
norm. emittance: < 0.8 mm*mrad	< 0.5 mm*mrad

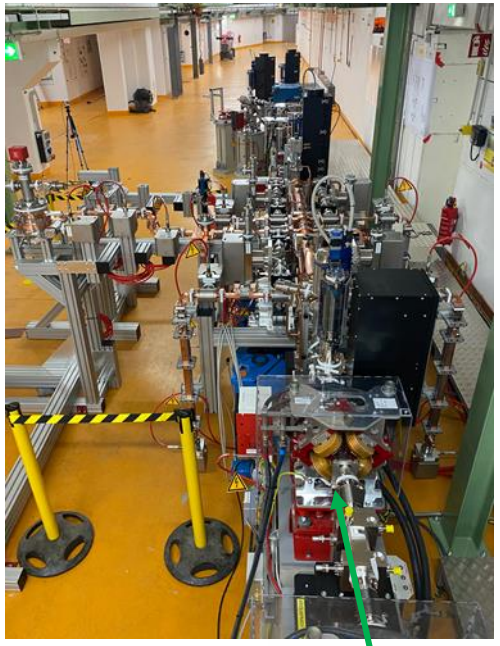
Courtesy: Florian Burkart

Contact: Florian Burkart, florian.burkart@desy.de

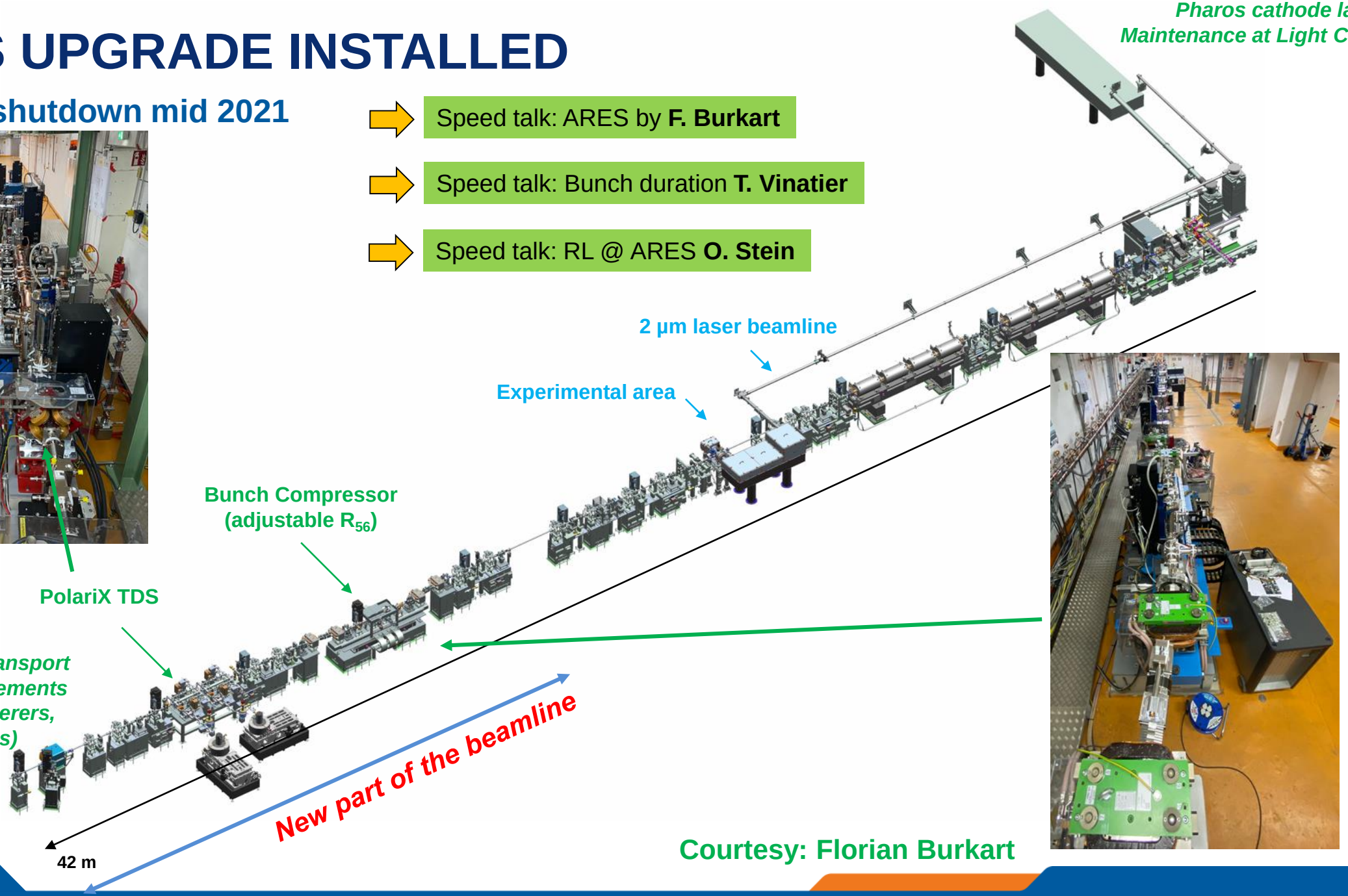
ARES UPGRADE INSTALLED

Pharos cathode laser: Maintenance at Light Conversion

3 month shutdown mid 2021



- Speed talk: ARES by **F. Burkart**
- Speed talk: Bunch duration **T. Vinatier**
- Speed talk: RL @ ARES **O. Stein**



Courtesy: Florian Burkart

Thanks to

Rainer Wanzenberg, Riccardo Bartolini, Ilya Agapov, Siggi Schreiber, Katja Hoonkavara, Juliane Roensch, Enrico Allaria, Winni Decking, Matthias Scholz, Riko Wichmann, Klaus Flottmann, Florian Burkart and many more ….

for material