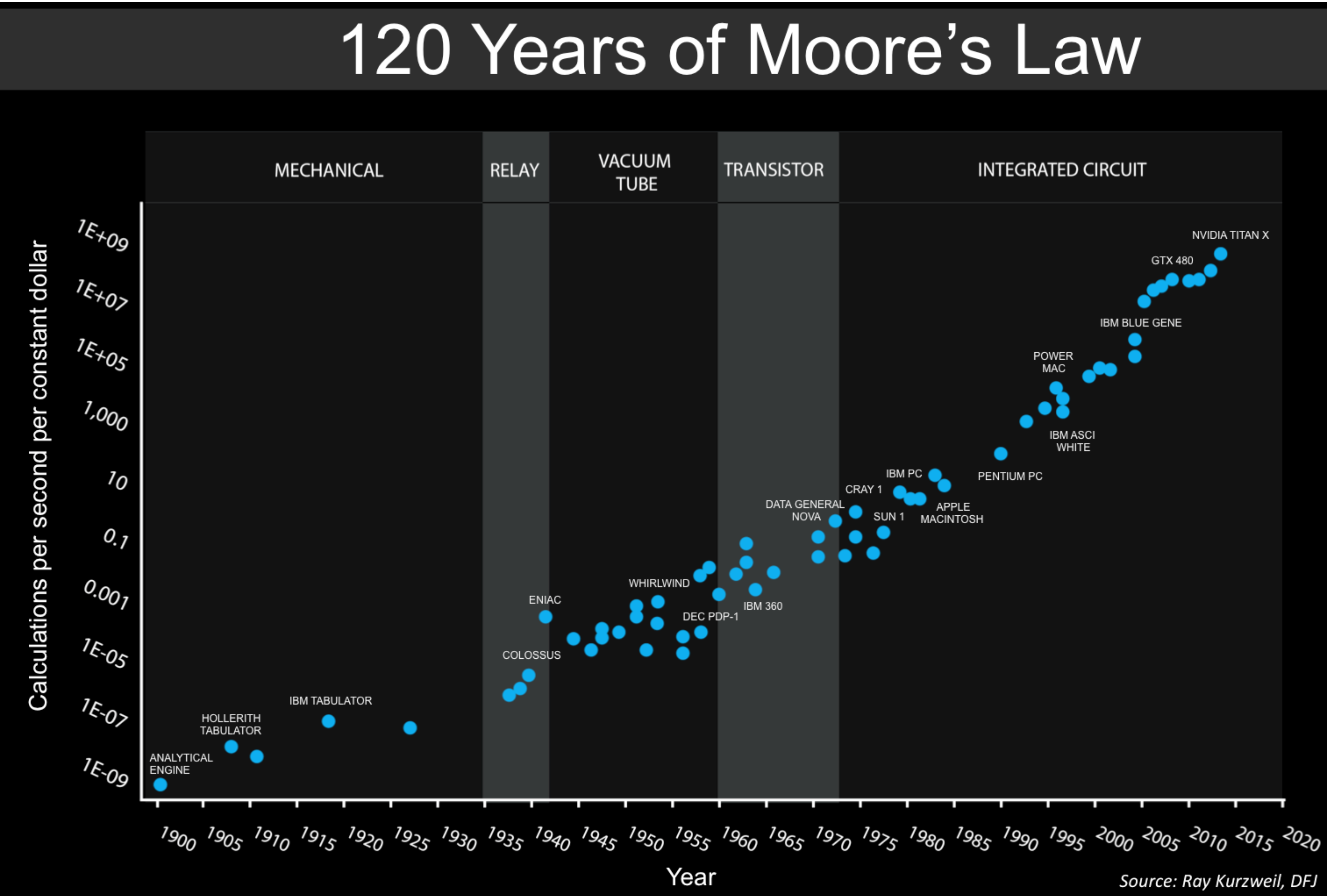
PAUL SCHERRER INSTITUT

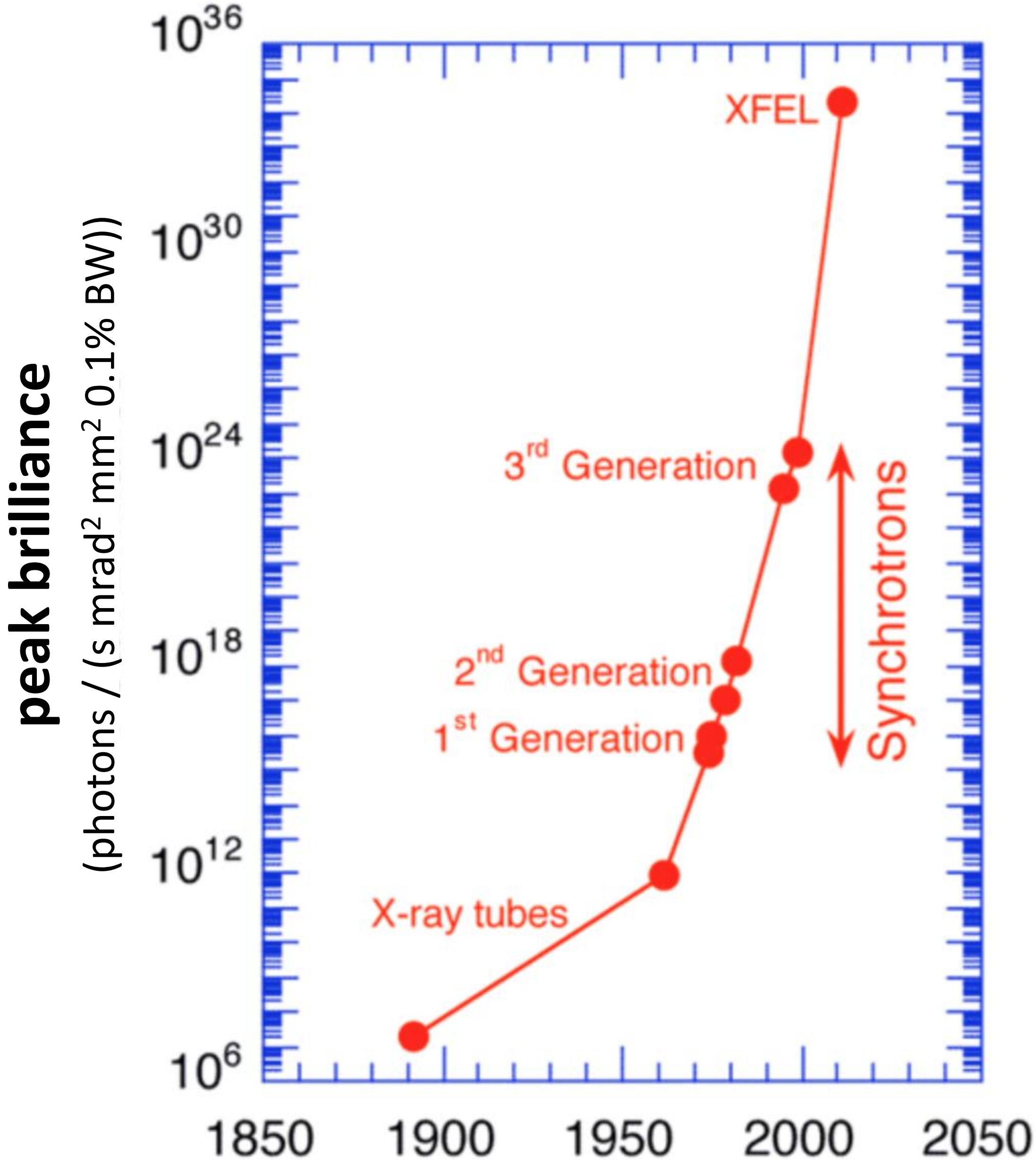
Florian Löhl :: Paul Scherrer Institut

Introduction to SwissFEL

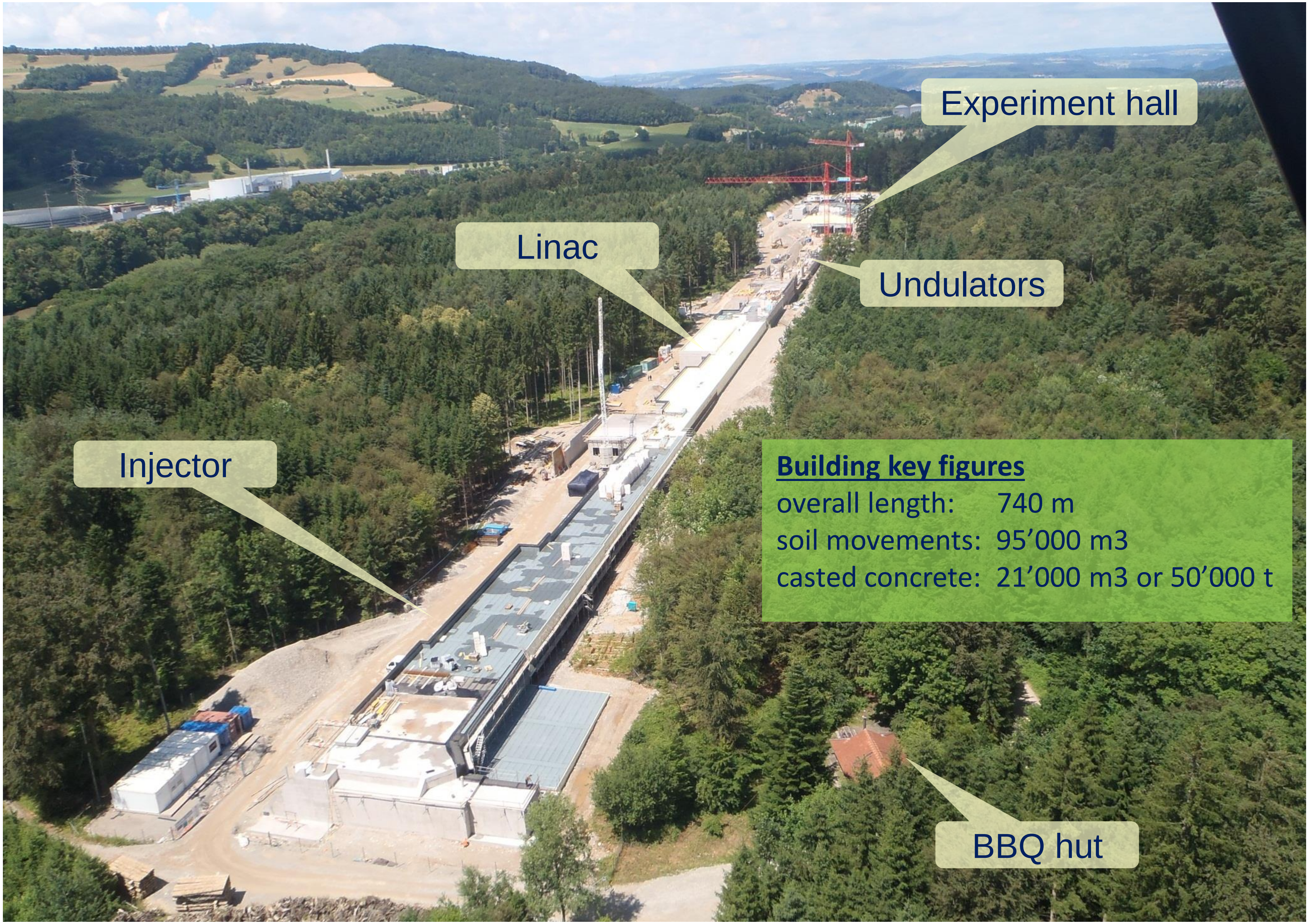
A very fast development…



An even faster development…



SwissFEL construction site (July 2014)



SwissFEL construction site (June 2015)

What is inside of the building?

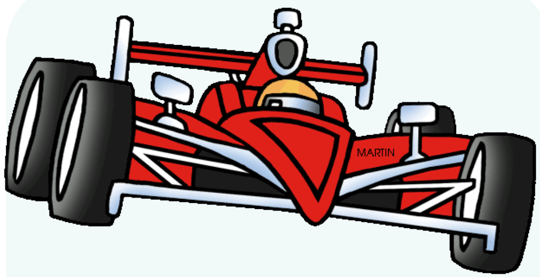
SwissFEL tunnel in spring 2015

Follow the SwissFEL beam

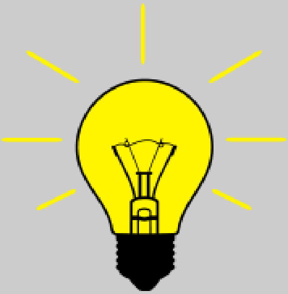
Total length: 736 m

000 m

What is inside of the building?



accelerator

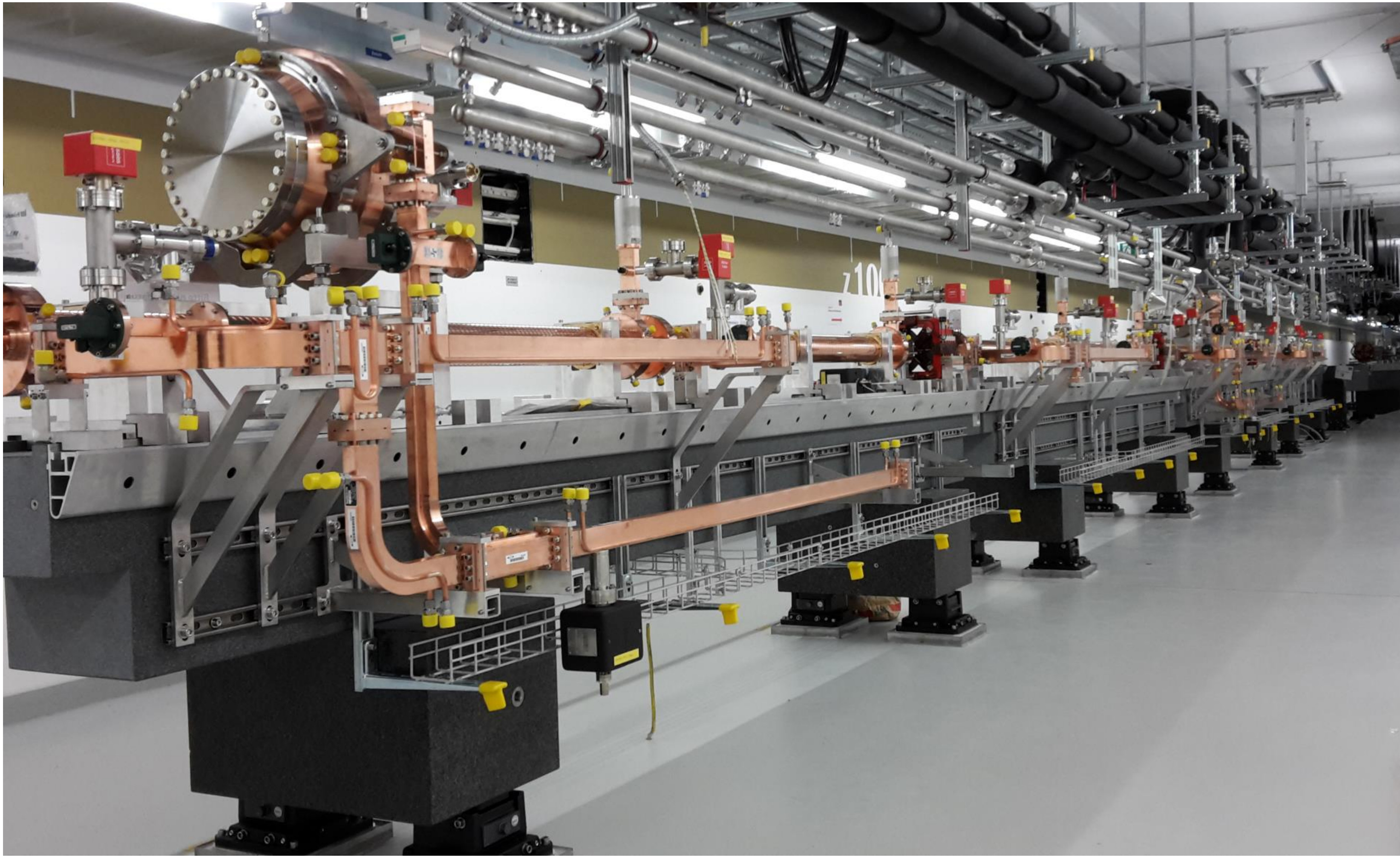


light generator

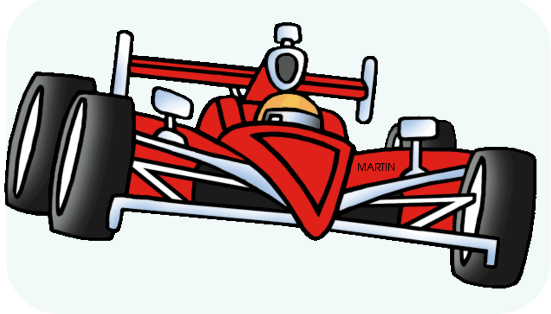
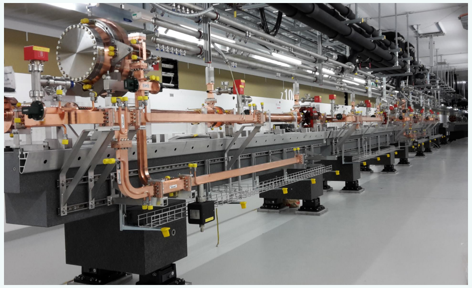
experimental station

The accelerator…

looks in reality like this:



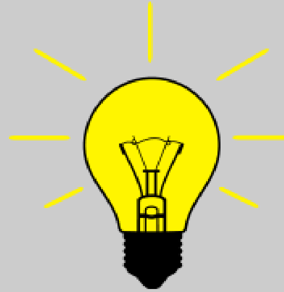
A comparison

		
Accelerated object	racing driver	electrons
Maximum acceleration	1.5 g	1.8×10^{18} g
Maximum velocity	370 km / h	300'000 km / s Nominal energy: 5.8 GeV reached: 18.9.2018
Gasoline consumption	43 l / 100 km	electric (50 µW / electron) (3 - 5 MW)

The light generator…

is in reality a slalom track with 7000 curves:

The payoff

		
Typical light power	ca. 5 W	50’000’000’000 W
Illuminated area	typ. many m^2	few μm^2 Corresponds to focus of all the energy the sun sends to earth to an area of 2 x 2 mm^2
Wavelength	ca. 500 nm	0.1 nm (≙ 12.4 keV)
Exposure time	CW	few (10) fs

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Comparison of different light sources

Optical short pulse lasers

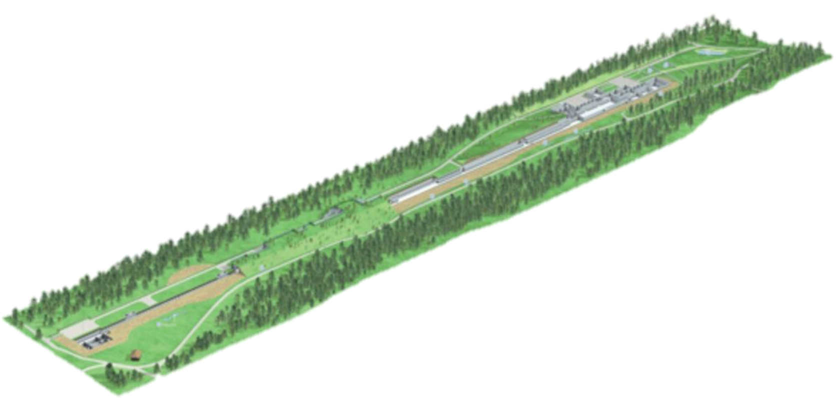
Pulse duration:	+++	(few fs)
Pulse energy:	+++	(many mJ)
Wavelength:	- - -	(~800 nm)

→ Fastest processes can be analyzed
→ Spatial resolution very limited

Synchrotrons

Pulse duration:	o	(few ps)
Pulse energy:	o	(< nJ)
Wavelength:	+++	(~ 0.1 nm)

→ Temporal resolution limited
→ Wavelength allows for atomic resolution

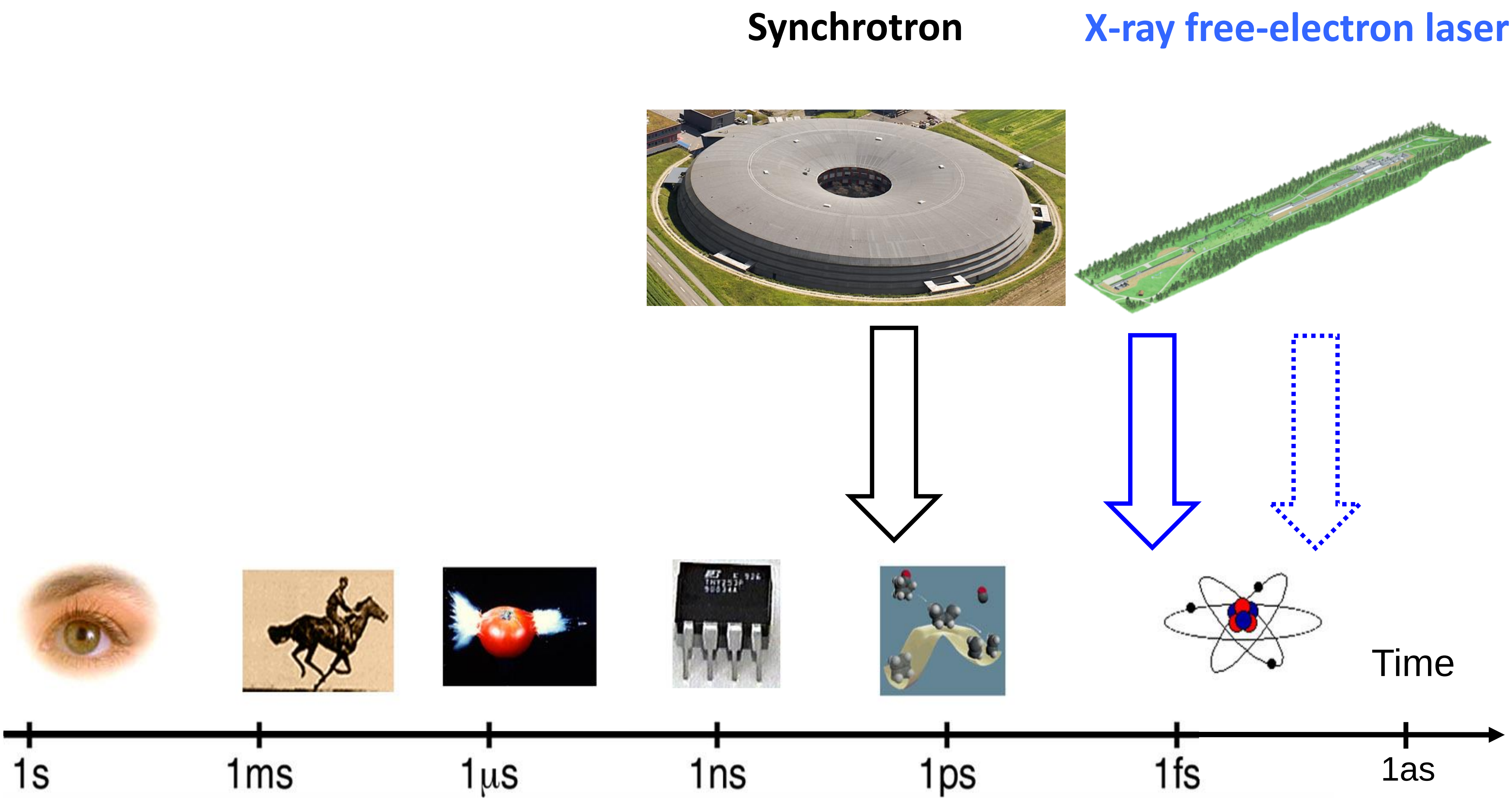


X-ray free-electron lasers

Pulse duration:	+++	(few fs)
Pulse energy:	++	(few mJ)
Wavelength:	+++	(~ 0.1 nm)

→ Fastest processes can be analyzed
→ Wavelength allows for atomic resolution

Time scales



- 1 picosecond = 1 ps = 10^{-12} s = 0.000000000001 s
- 1 femtosecond = 1 fs = 10^{-15} s = 1 ps / 1000 = 0.000000000000001 s
- 1 attosecond = 1 as = 10^{-18} s = 1 fs / 1000 = 0.000000000000000001 s

The importance of the exposure time

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The importance of the exposure time

www.bitblokes.de

Principle of an accelerator-based light source

- When charged particles are accelerated, they emit light
- 'Bending' a particle beam is an acceleration:

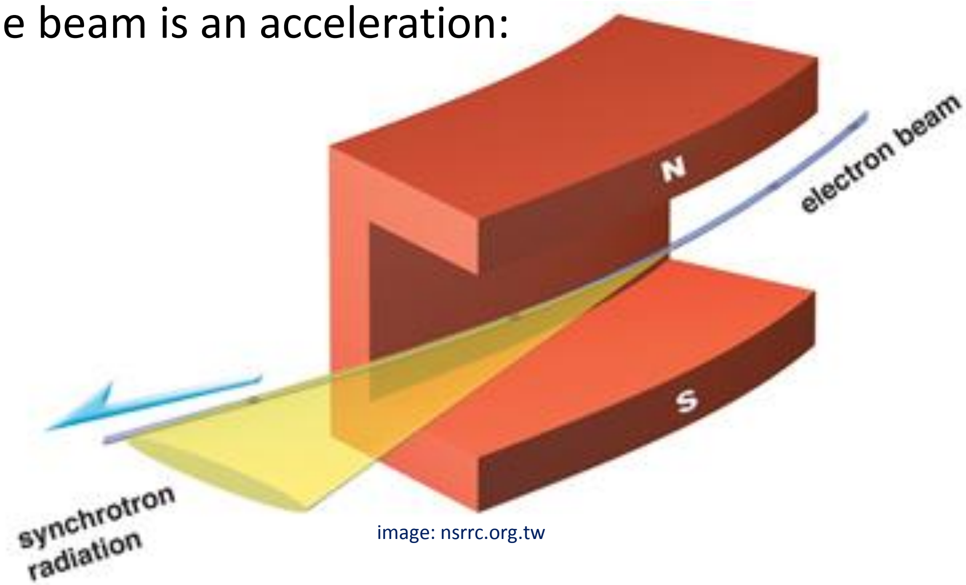


image: nsrrc.org.tw

- The most efficient magnets for this process are so-called undulators:

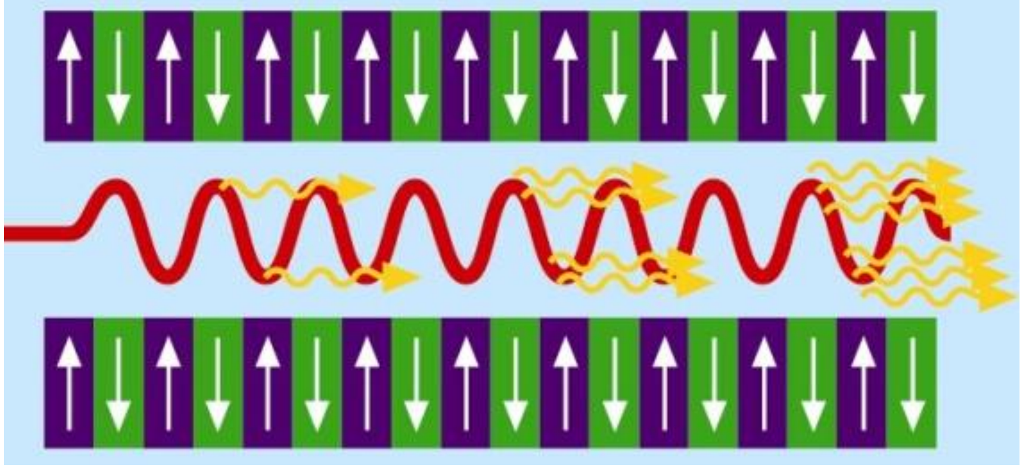
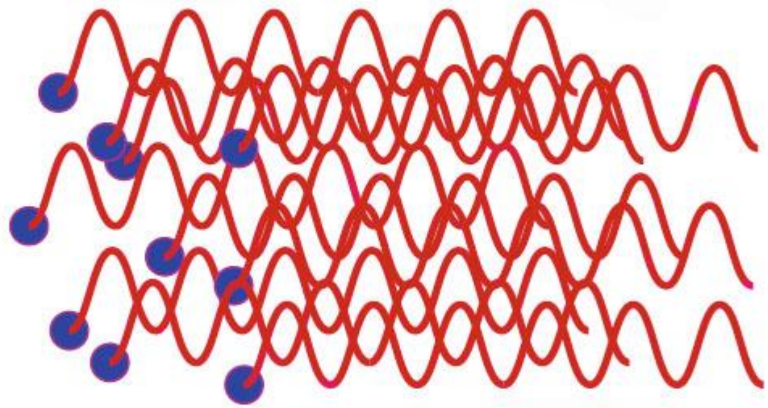


image: desy.de

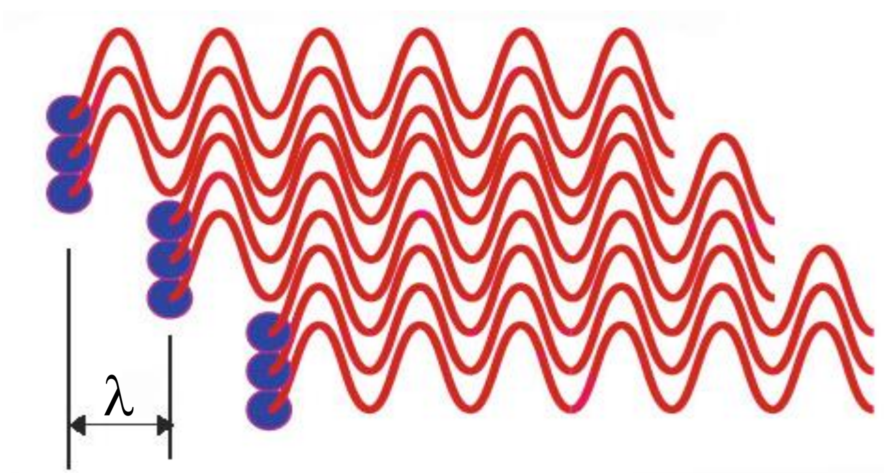
Loss in efficiency of the 'normal' light from an undulator:



$$E \propto \sqrt{N}$$

$$I \propto N$$

What if we could arrange the electrons such that they would all radiate in phase?

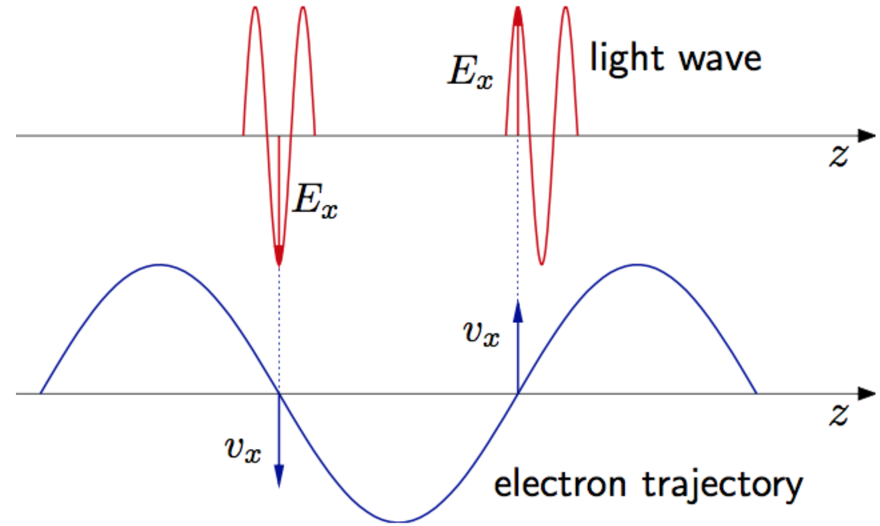


$$E \propto N$$

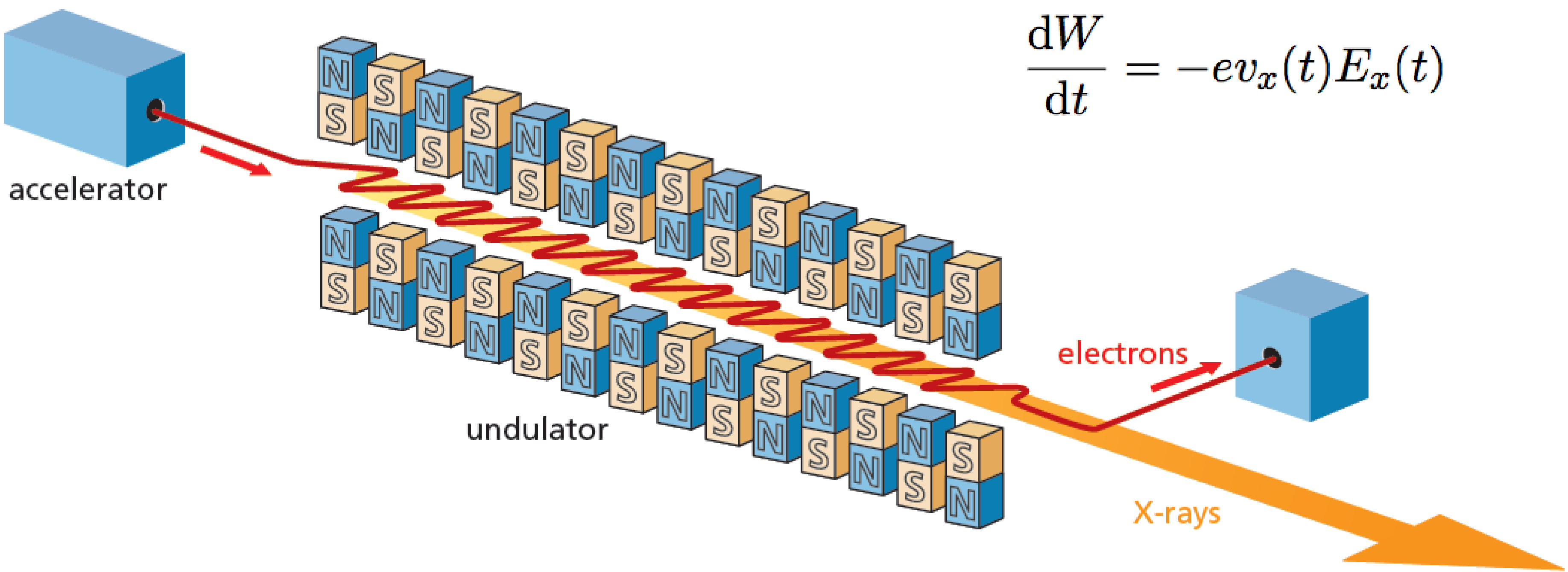
$$I \propto N^2$$

How does a free-electron laser work?

- A **<u>very long undulator</u>** is used
- A **<u>very good electron beam</u>** is required
- At the beginning of the undulator, the electrons emit light
- This light interacts with the electron beam
- This causes an exponential growth of the emitted light



$$\frac{\mathrm{d}W}{\mathrm{d}t} = -e v_x(t) E_x(t)$$



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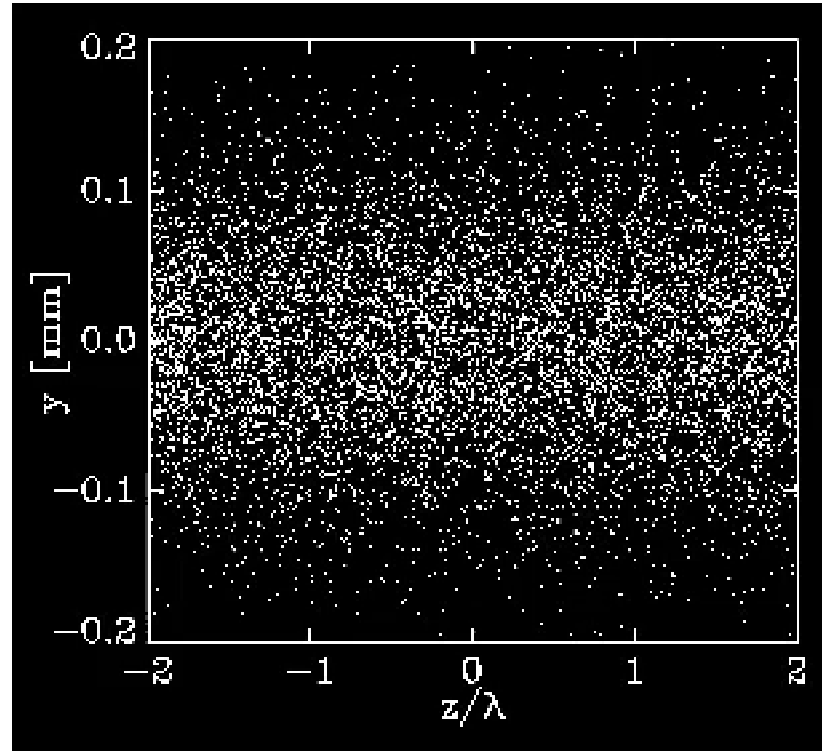
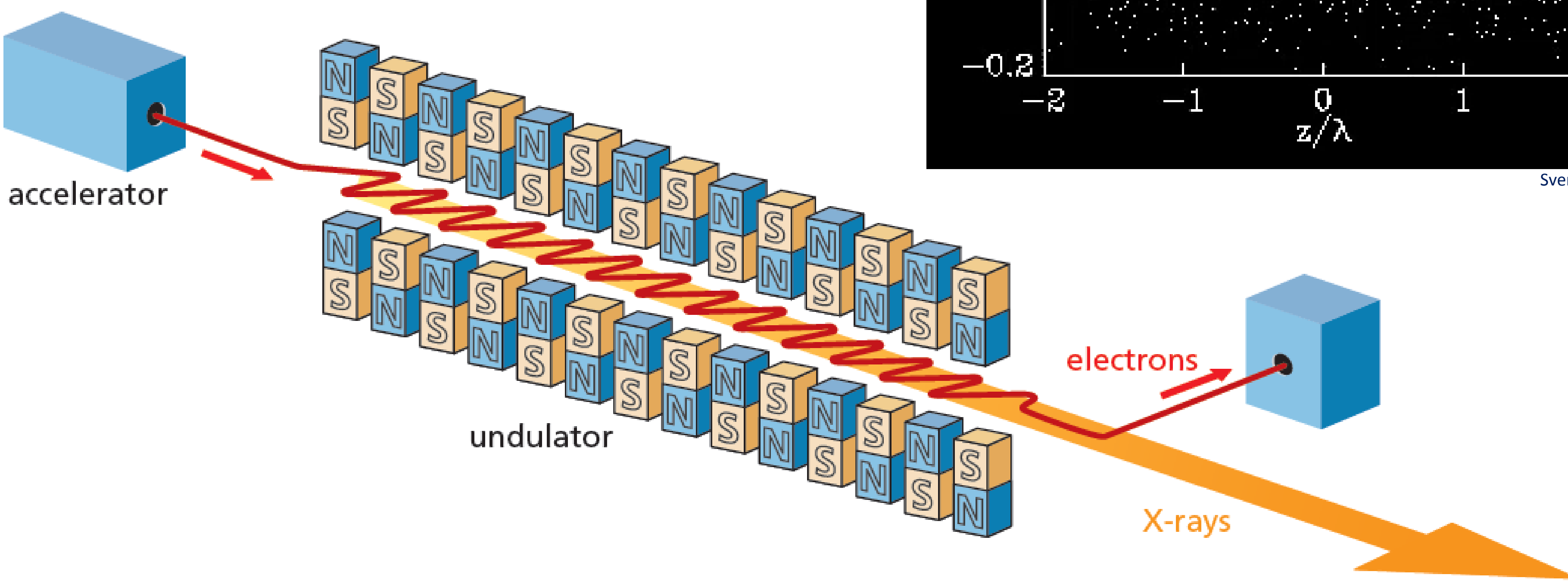
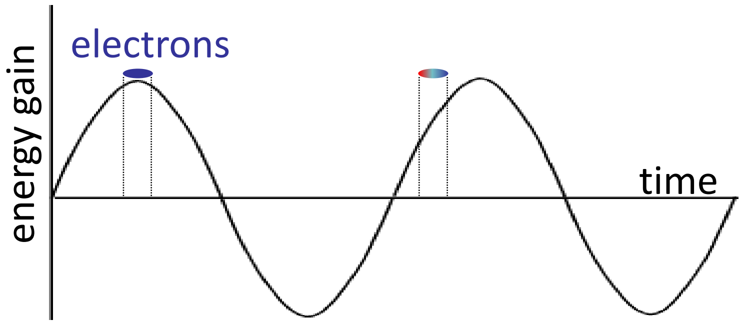


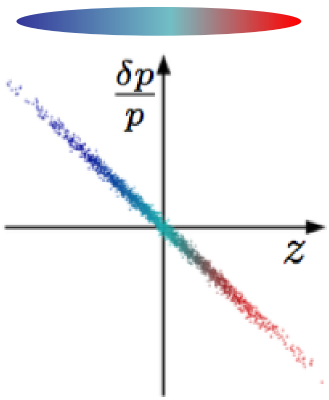
Sven Reiche



How do you generate femtosecond electron bunches

Acceleration of electrons in accelerating structures:





The first x-ray source (Röntgen, 1895)

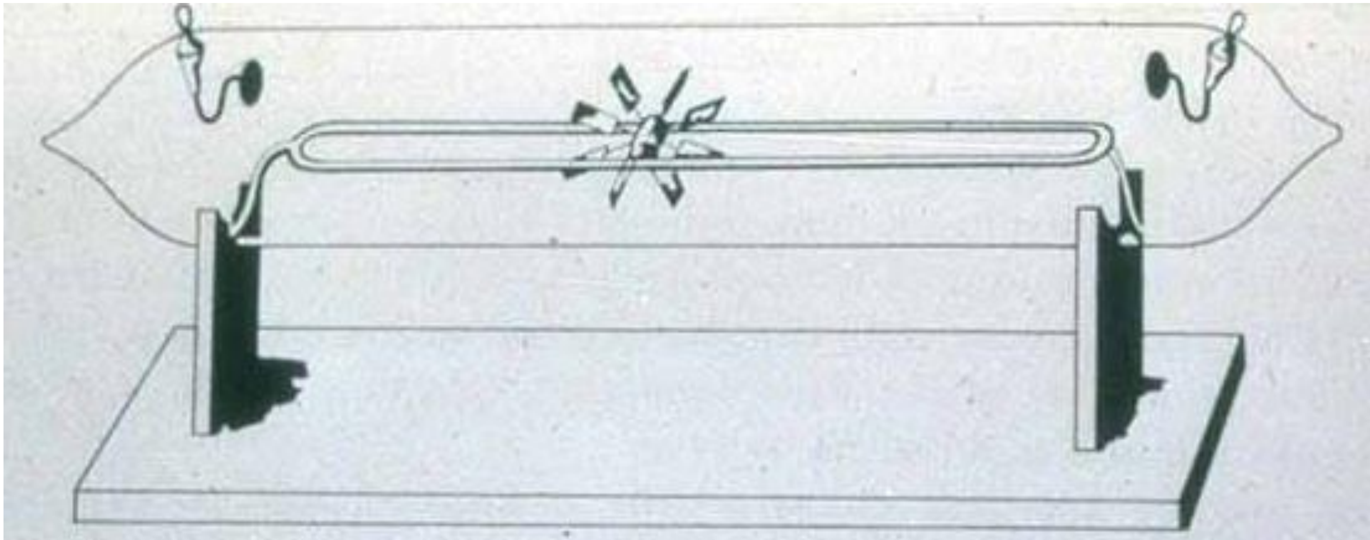
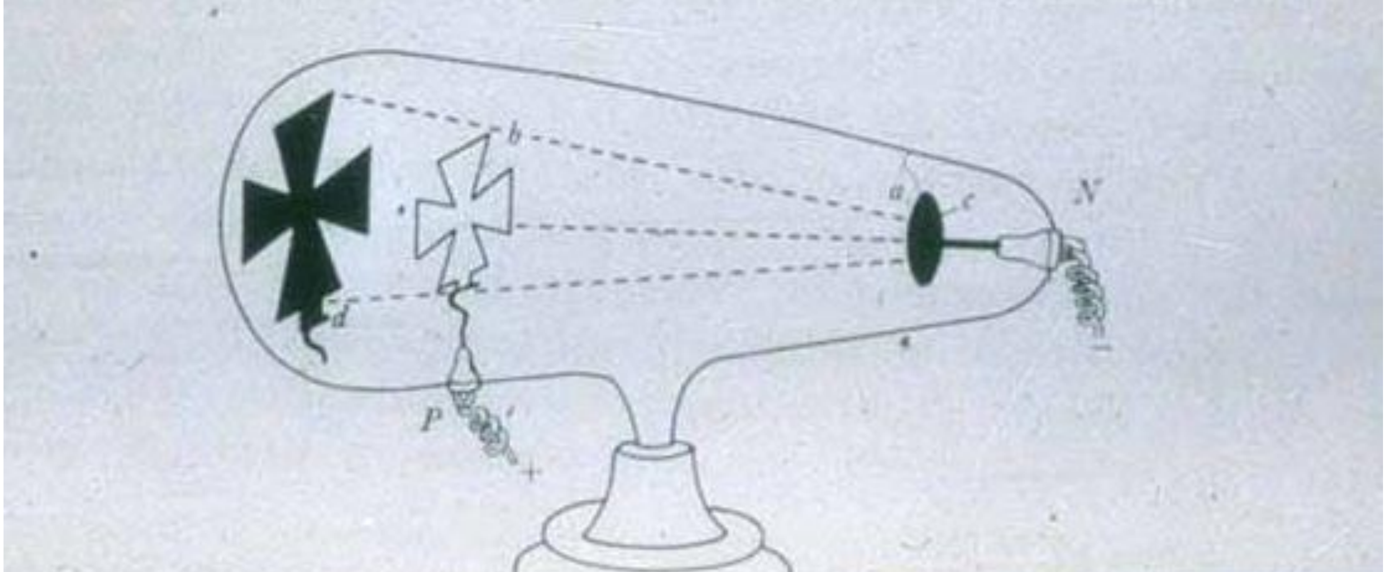
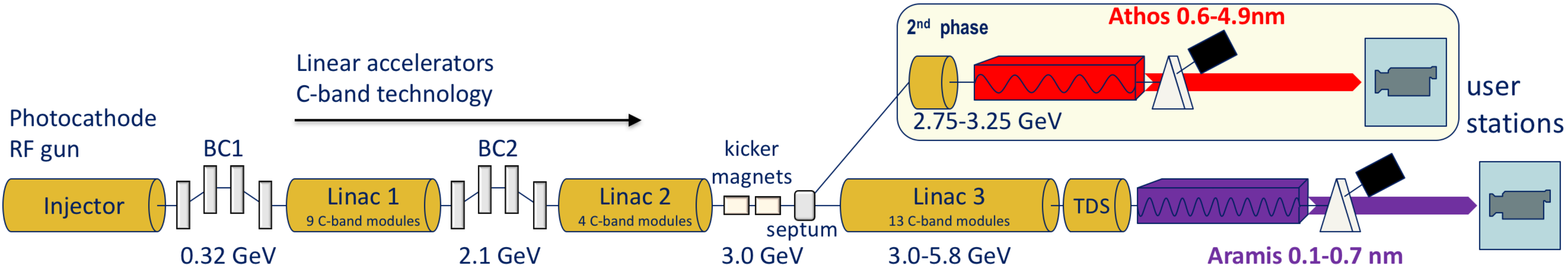


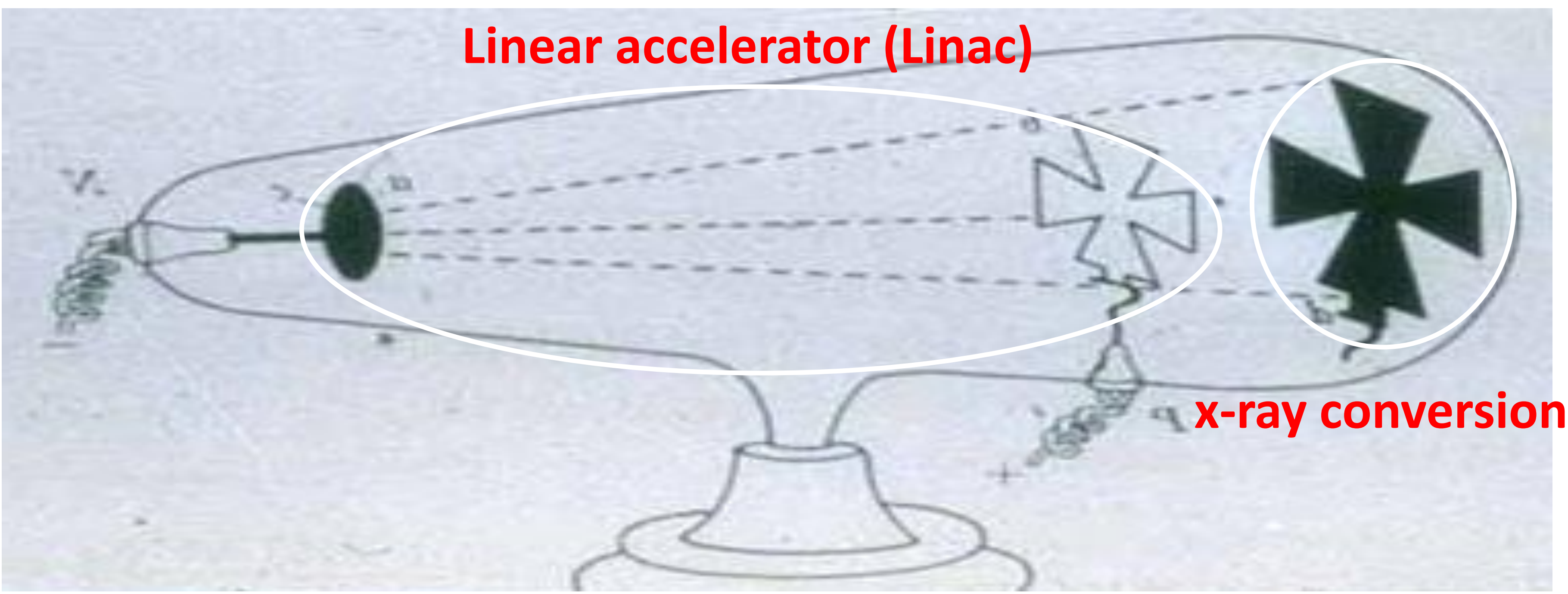
FIG. 1. From *Electrical Engineer* (*New York*), *21*: 237, March 4, 1896.



SwissFEL

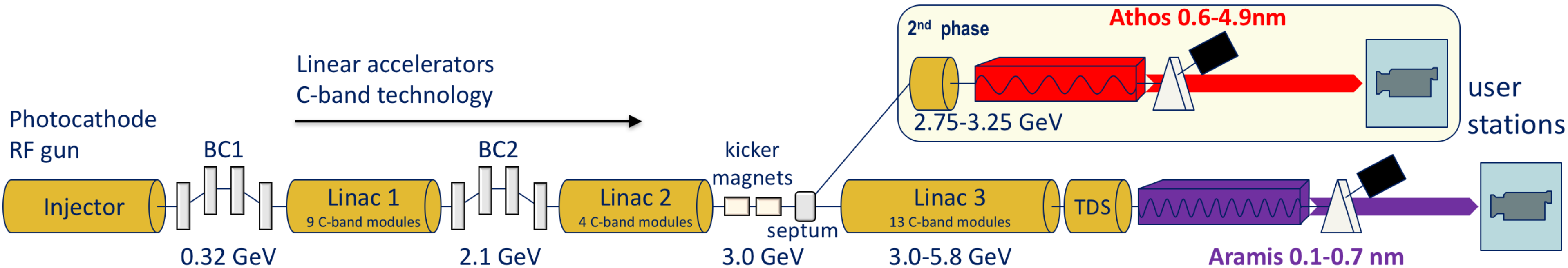


Linear accelerators
C-band technology
Photocathode
RF gun
BC1
BC2
kicker
magnets
septum
2nd phase
Athos 0.6-4.9nm
2.75-3.25 GeV
user
stations
Injector
Linac 1
9 C-band modules
Linac 2
4 C-band modules
Linac 3
13 C-band modules
TDS
0.32 GeV
2.1 GeV
3.0 GeV
3.0-5.8 GeV
Aramis 0.1-0.7 nm



Linear accelerator (Linac)
x-ray conversion

SwissFEL



ARAMIS

Hard X-ray FEL, λ=0.1-0.7 nm
Linear polarization, variable gap, in-vacuum undulators
First users 2017
Operation modes: SASE & self seeded

ATHOS

Soft X-ray FEL, λ=0.6-4.9 nm
Variable polarization, Apple-X undulators (2 m length)
First users 2020?
Operation modes: SASE & self seeded & many more

Main parameters

Wavelength from	0.1nm–4.9nm
Photon energy	0.25-12 keV
Pulse duration	1 fs - 20 fs
e^- Energy (0.1 nm)	5.8 GeV
e^- Bunch charge	10-200 pC
Repetition rate	100 Hz

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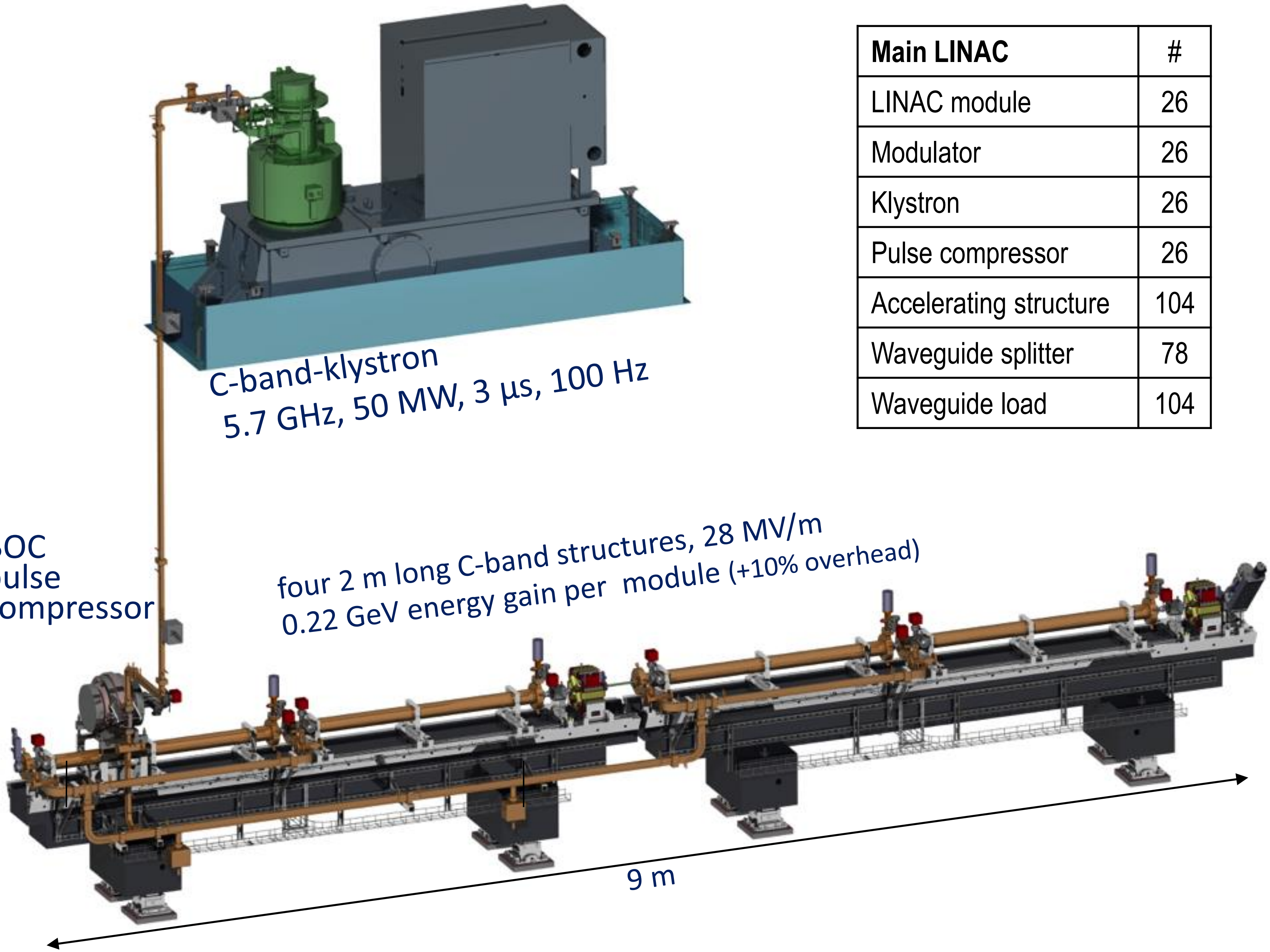
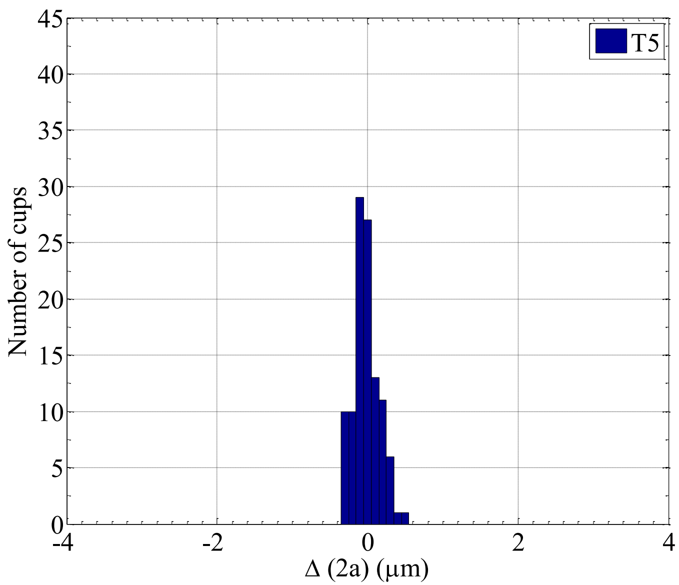
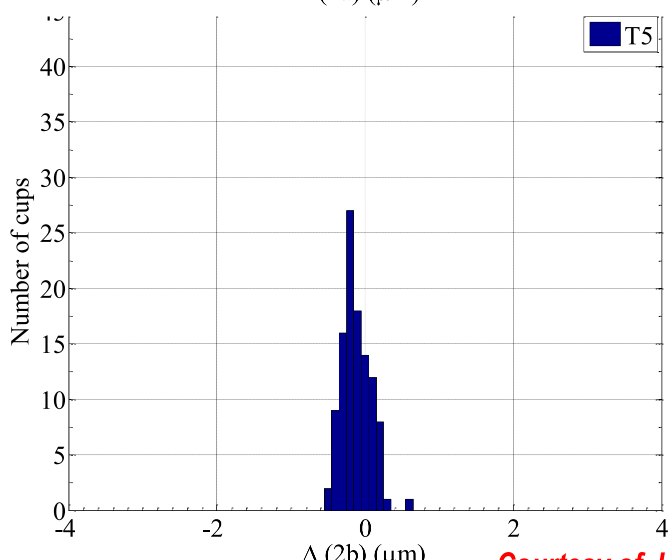
The SwissFEL main linac

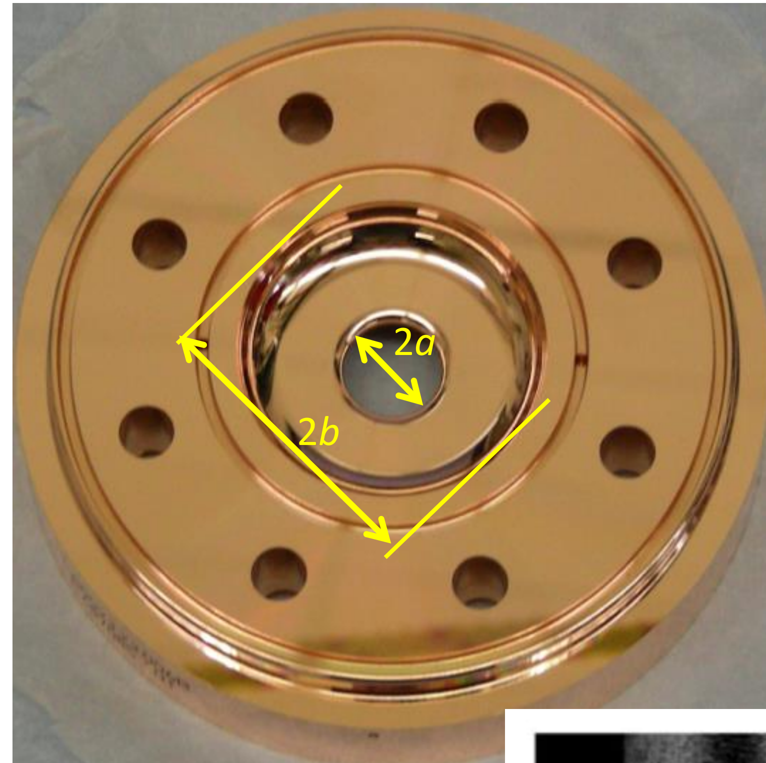


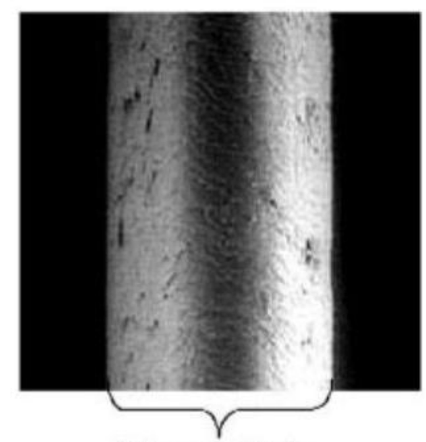
Main LINAC	#
LINAC module	26
Modulator	26
Klystron	26
Pulse compressor	26
Accelerating structure	104
Waveguide splitter	78
Waveguide load	104

Precision manufacturing of copper disks in Trübbach







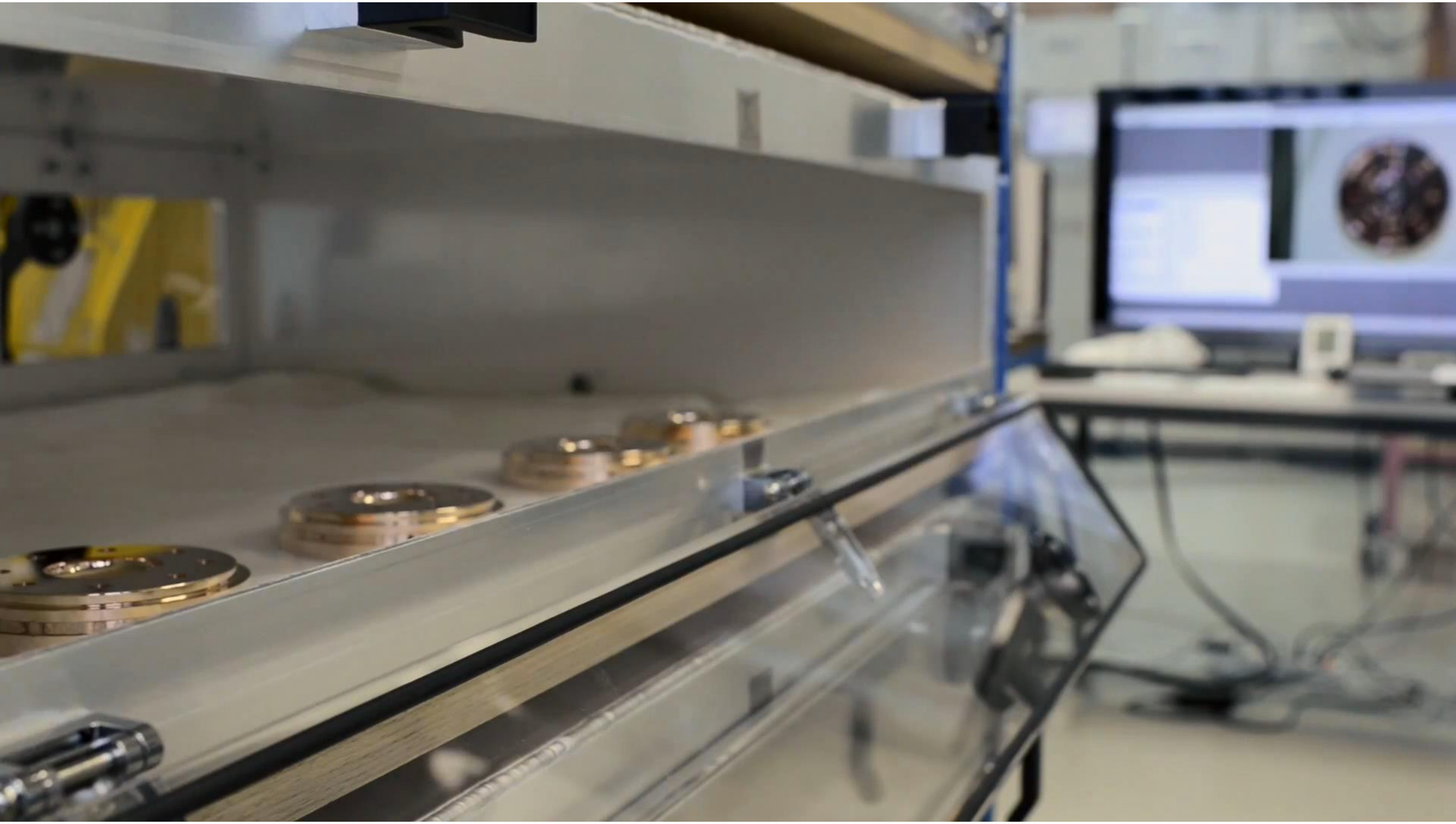


Human Hair
(60 μm diameter)

Courtesy of J.Y. Raguin

Typical examples of metrology on a structure:
Top: histogram iris diameter; Bottom: histogram iris cell diameter

Assembly of an accelerator structure at PSI



C-band module assembly

Girders were pre-assembled in a storage hutch

C-band module assembly

Movement of girder into assembly hutch

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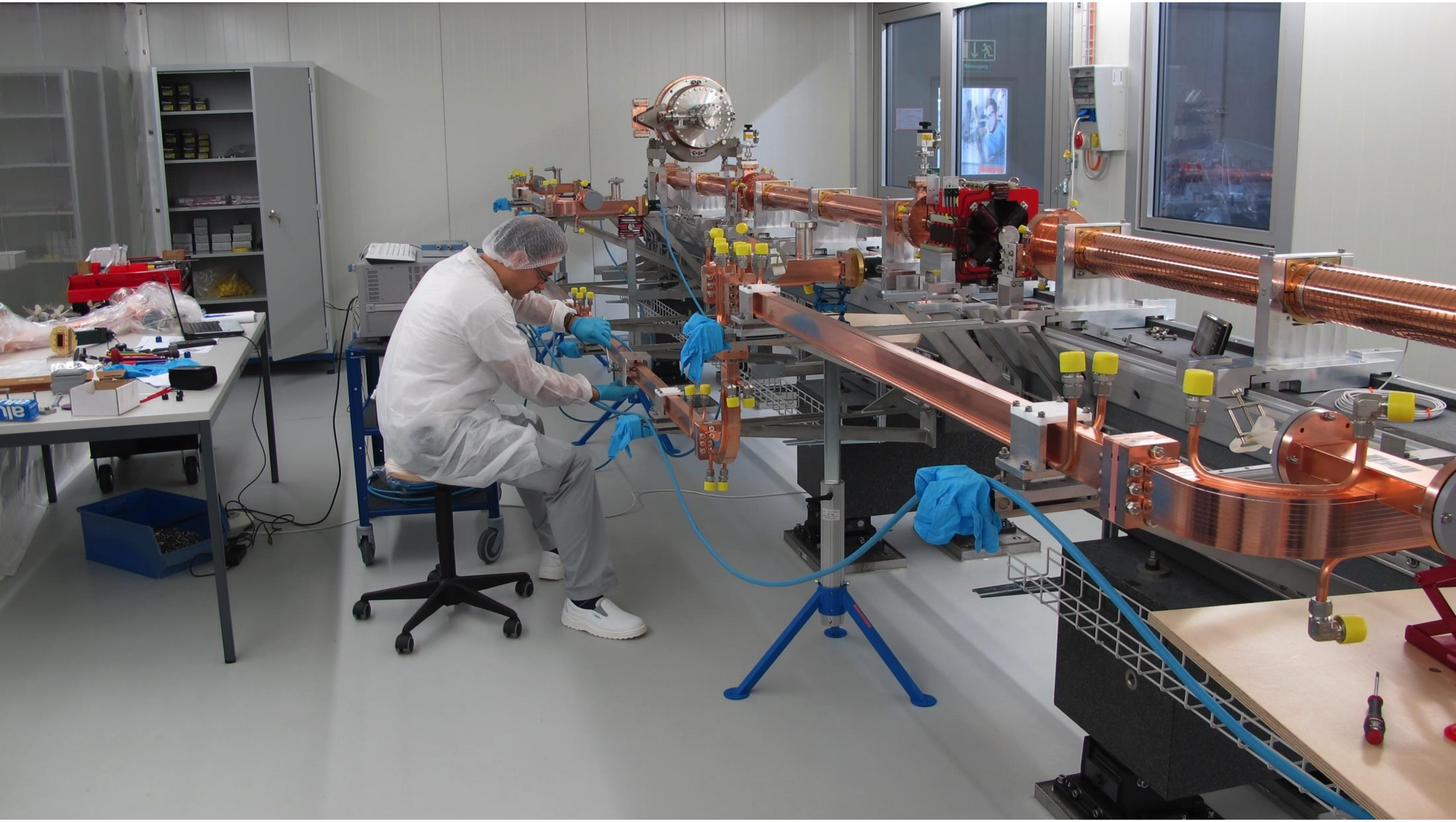
C-band module assembly

Installation of girders into assembly hutch

C-band module assembly



Installation and tuning of waveguides (waveguides delivered from MHI-MS)

Girder installation in SwissFEL

Accelerator module in the SwissFEL tunnel

SwissFEL undulators

Transport of undulators in SwissFEL building
with air-cushion vehicle

Courtesy of Romain Ganter

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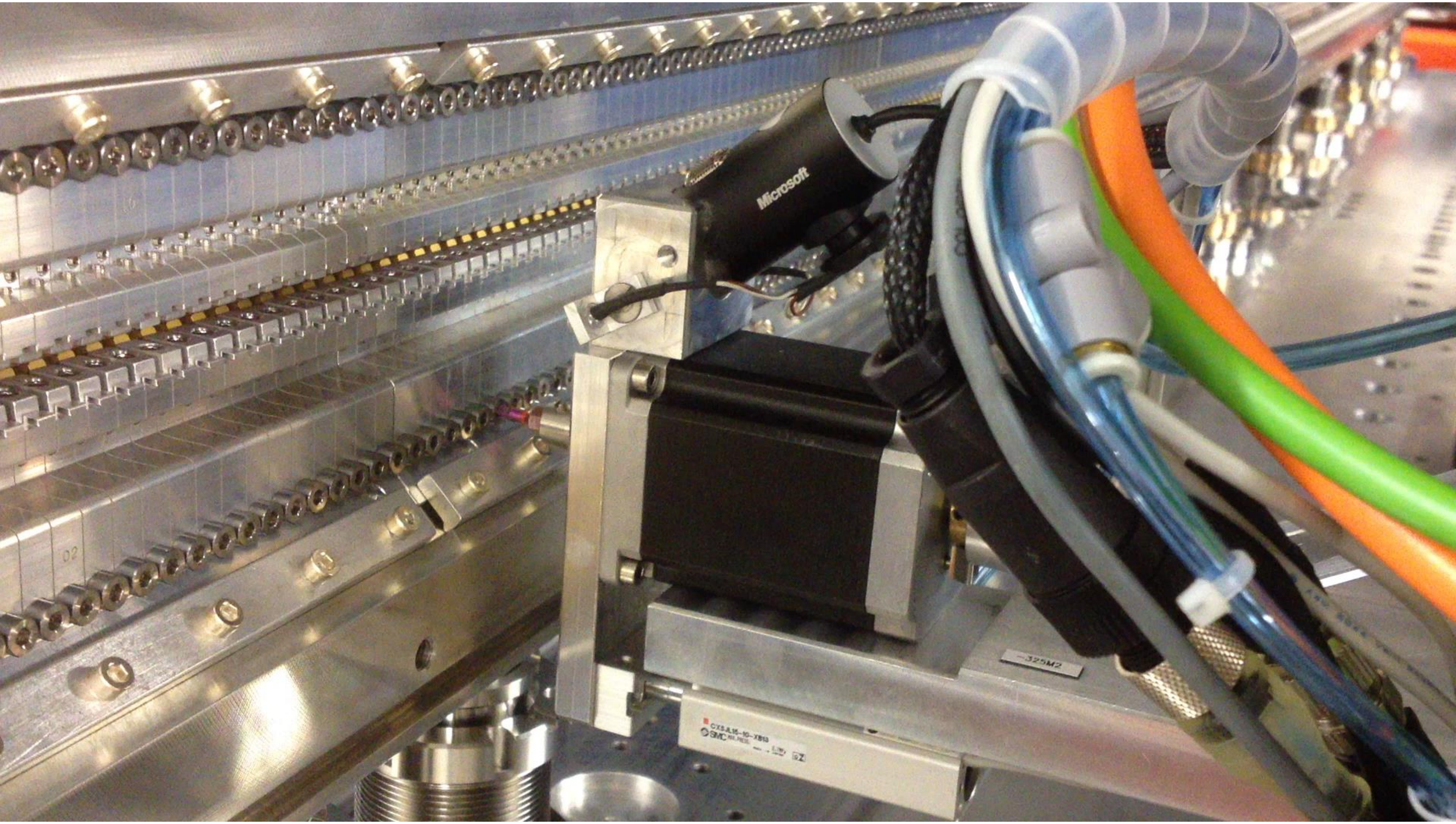
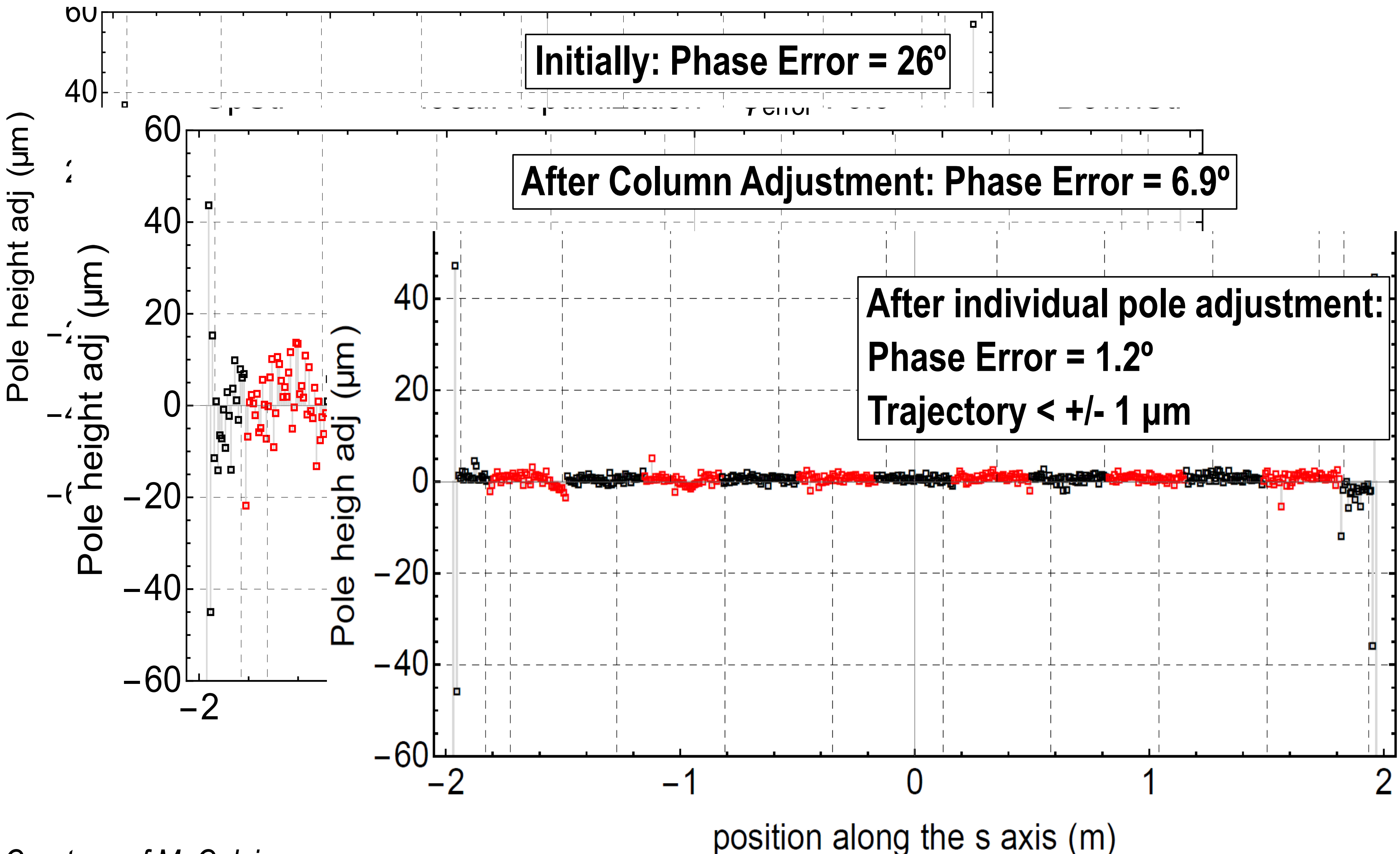
Adjustment of the undulator magnets



Effect of the adjustments on the field errors



Courtesy of M. Calvi

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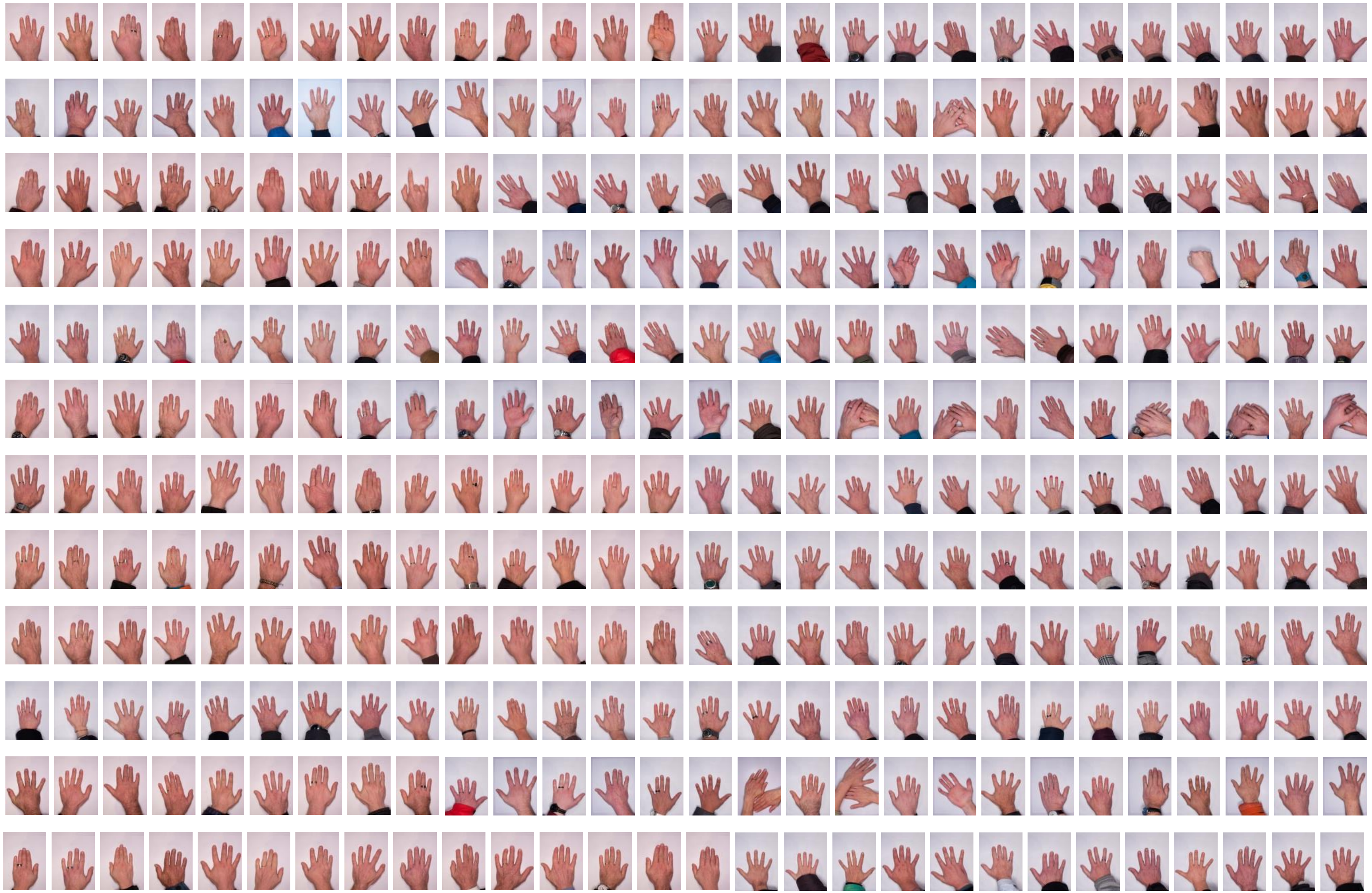
Thank you for your attention!



Thank you for your attention!

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Summer student position

https://www.psi.ch/en/pa/job-opportunities/32415-trainee

Trainee

Performance optimization of the free-electron laser SwissFEL

Your tasks

During the last years, an optimizer was used during the operation of SwissFEL which generated large sets of data of the optimization process. Your task will be to analyze the existing sets of data and to further extend the existing optimizer by additional optimization routines that will allow for a faster and more stable convergence. An example is the implementation of 'shallow learning', but many interesting options exist, and you will help trying out the most promising alternatives. You will learn about accelerators, free-electron lasers, data analysis, and multi-parameter optimization.

Your profile

- You study physics or computer-sciences (minimum 4 semesters)
- You have an interest in analyzing data, programming, and testing your work on the accelerator of SwissFEL
- Experience with programming in C++ and scripting languages such as Matlab or python is desired
- You are open-minded, communicative and enjoy working in an international team
- You have not yet completed your Master's thesis

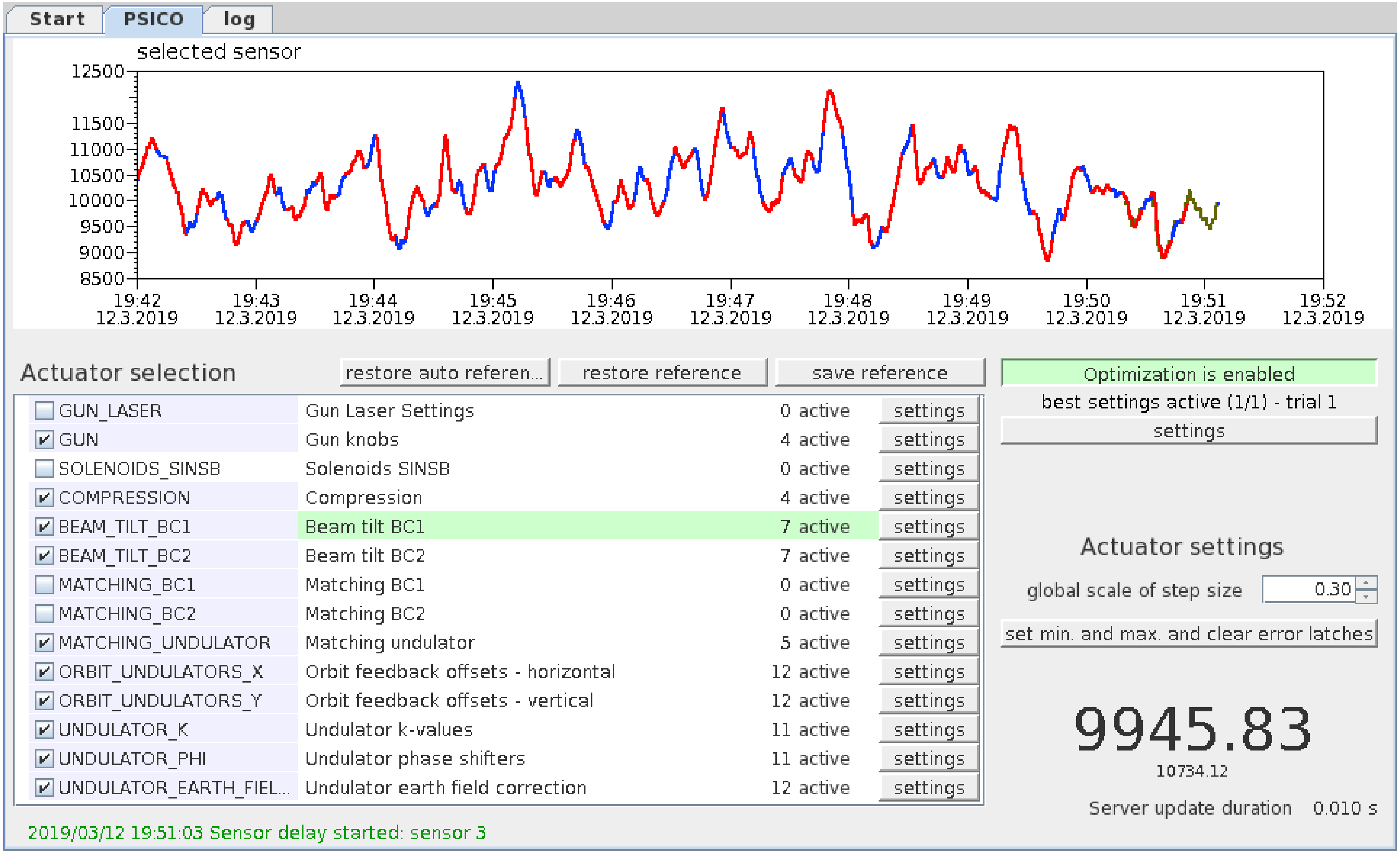
We offer

Our institution is based on an interdisciplinary, innovative and dynamic collaboration.

The contract will be limited to 3 months.

For further information, please contact Dr Florian Löhl, phone +41 56 310 35 26.

PSICO – automated machine optimization



Example of PSICO tuning at 9 keV