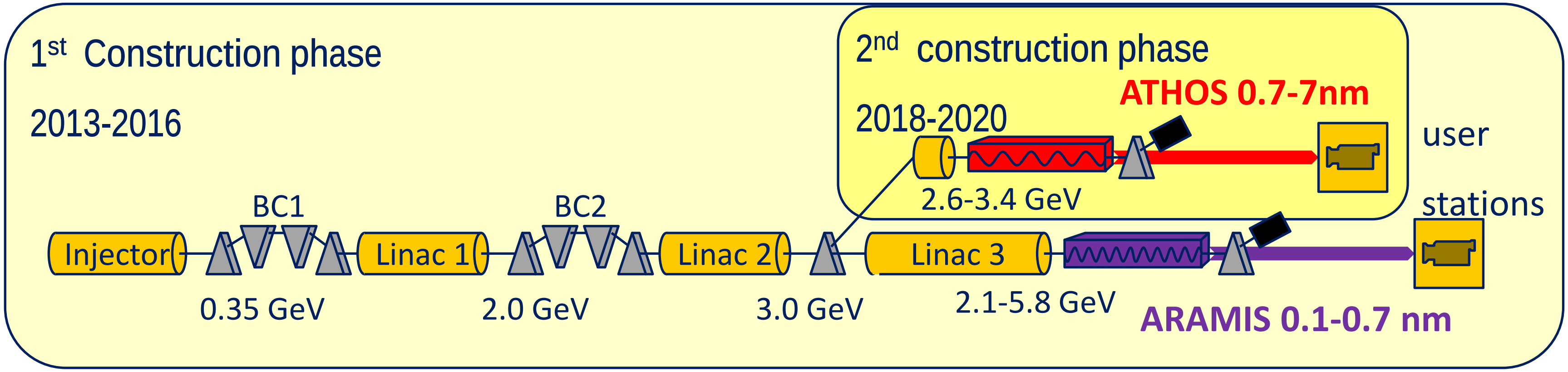
Rafael Abela:: SwissFEL Photonics :: Paul Scherrer Institut

SwissFEL Status
Resarch Opportunities

Users Meeting, December 6 2016

SwissFEL in a nutshell



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=0.65 - 5.0 nm
- Variable polarization undulators
- First users 2020
- Operation modes: SASE + self seeded + CHIC +…

Main parameters

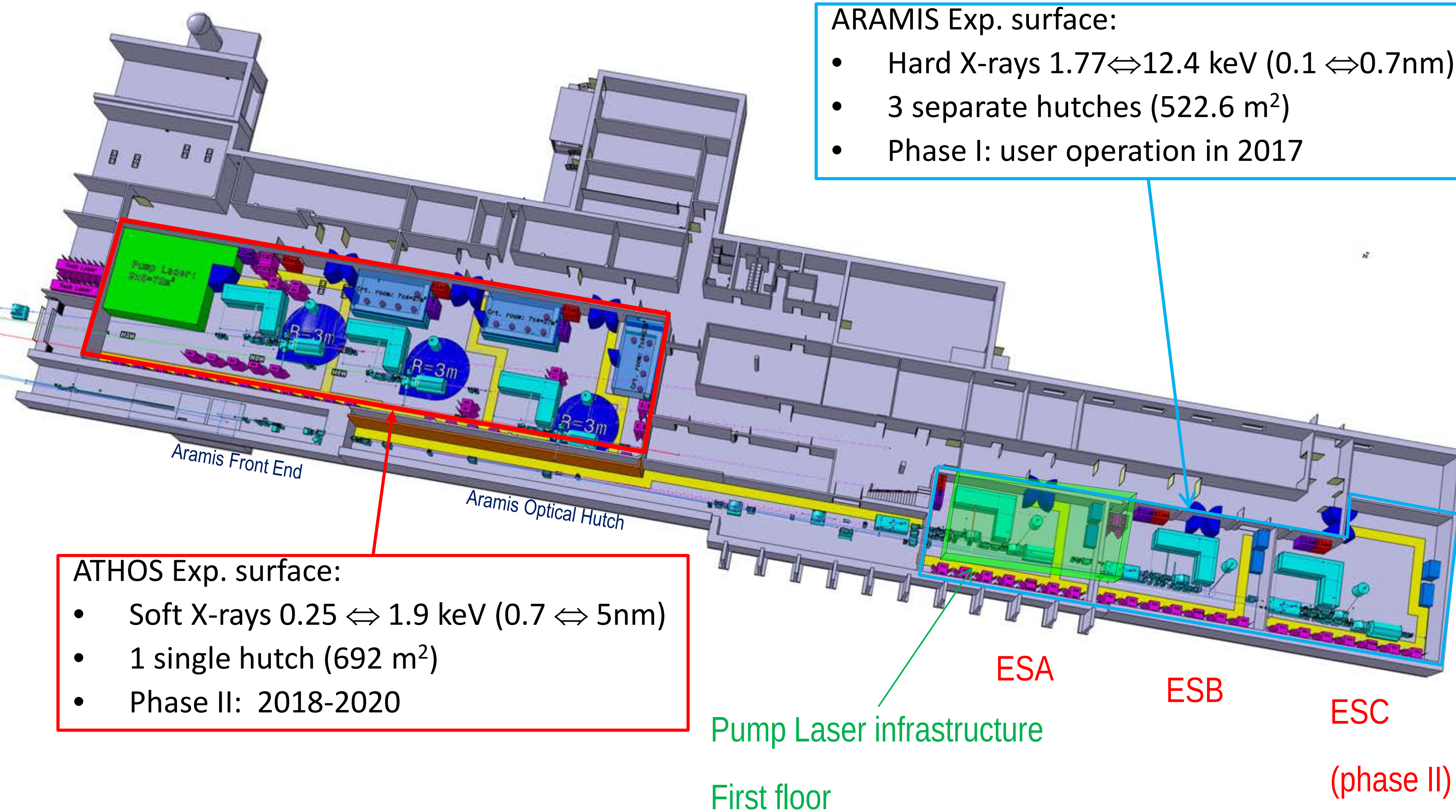
Wavelength from	0.1nm–5nm
Photon energy	0.25-12 keV
Pulse duration	1 fs - 20 fs
e^- Energy (0.1 nm)	5.8 GeV
e^- Bunch charge	10-200 pC
Repetition rate	100 Hz

Jan'16 first users of game crossing observed

Overview Experimental Area

ARAMIS Exp. surface:

- Hard X-rays 1.77⇔12.4 keV (0.1 ⇔0.7nm)
- 3 separate hutches (522.6 m^2)
- Phase I: user operation in 2017

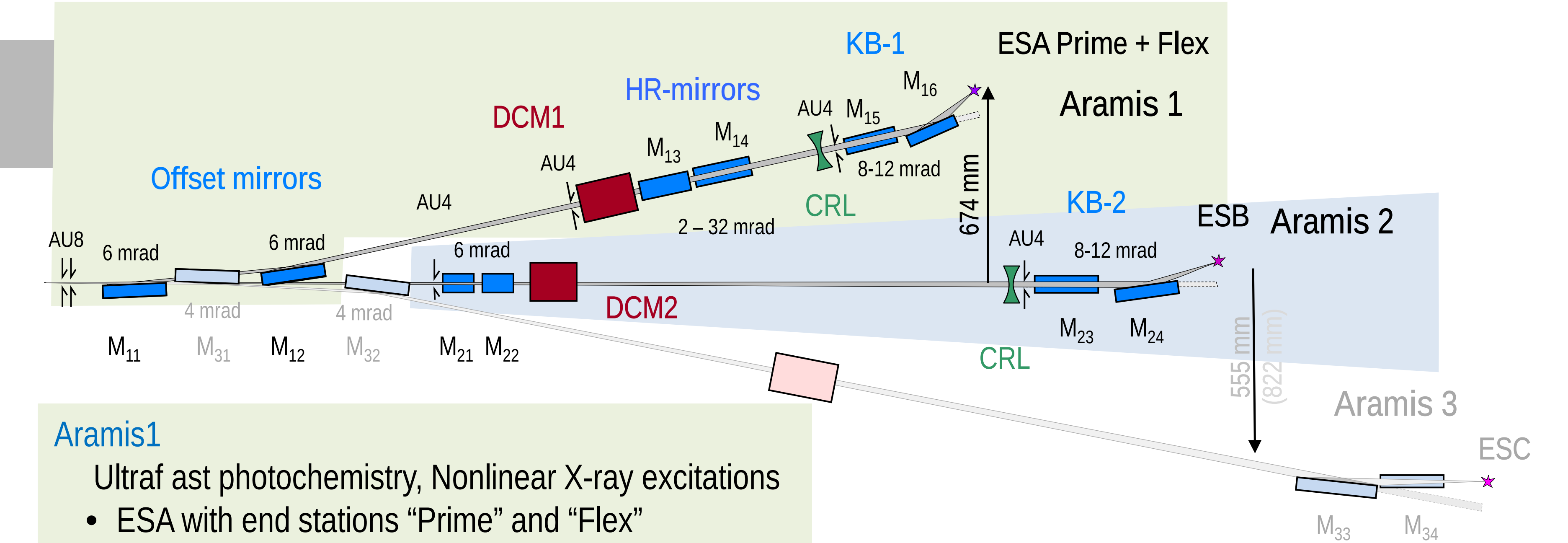


ATHOS Exp. surface:

- Soft X-rays 0.25 ⇔ 1.9 keV (0.7 ⇔ 5nm)
- 1 single hutch (692 m^2)
- Phase II: 2018-2020

ARAMIS Photon Beamline Layout

courtesy Rolf Follath



Aramis1

Ultrafast photochemistry, Nonlinear X-ray excitations

- ESA with end stations “Prime” and “Flex”
- Harmonic rejection < 10^{-5}
- 1.5 m / 4 m working distance
- Prime focus : <1 µm (ideal optics @12.4 keV)
  Flex focus : 1.5 µm (ideal optics @12.4 keV)

Aramis 2

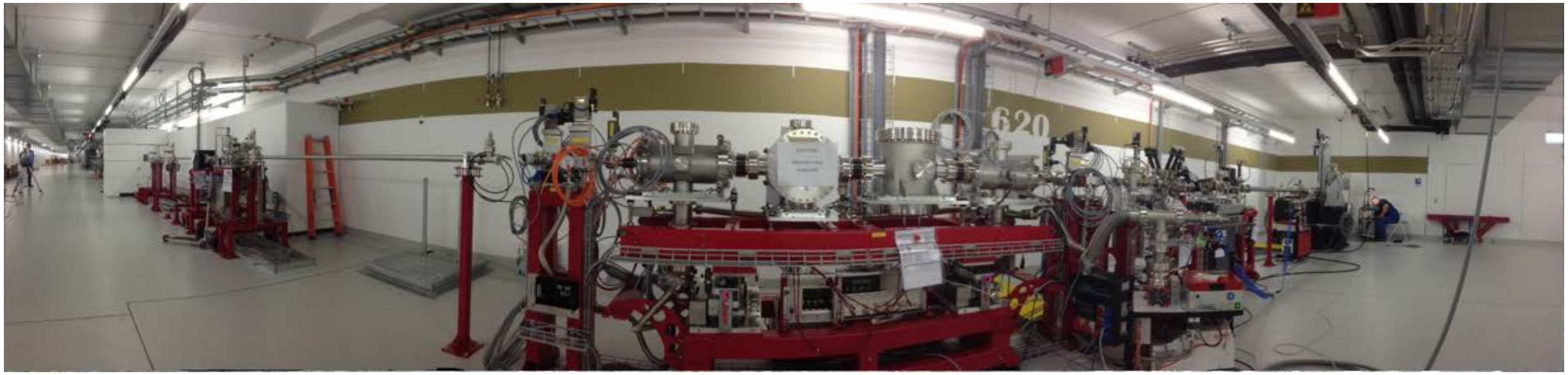
Pump Probe Diffraction and Scattering

- Grazing incidence (resonant) X-ray diffraction
- 2.5 m working distance
- 2-200 µm spot size
- 1 µm focus size (Ideal optics @ 12.4 keV)

Photon energy range

1.7 – 12.4 keV (1- 7 Å)

Front End



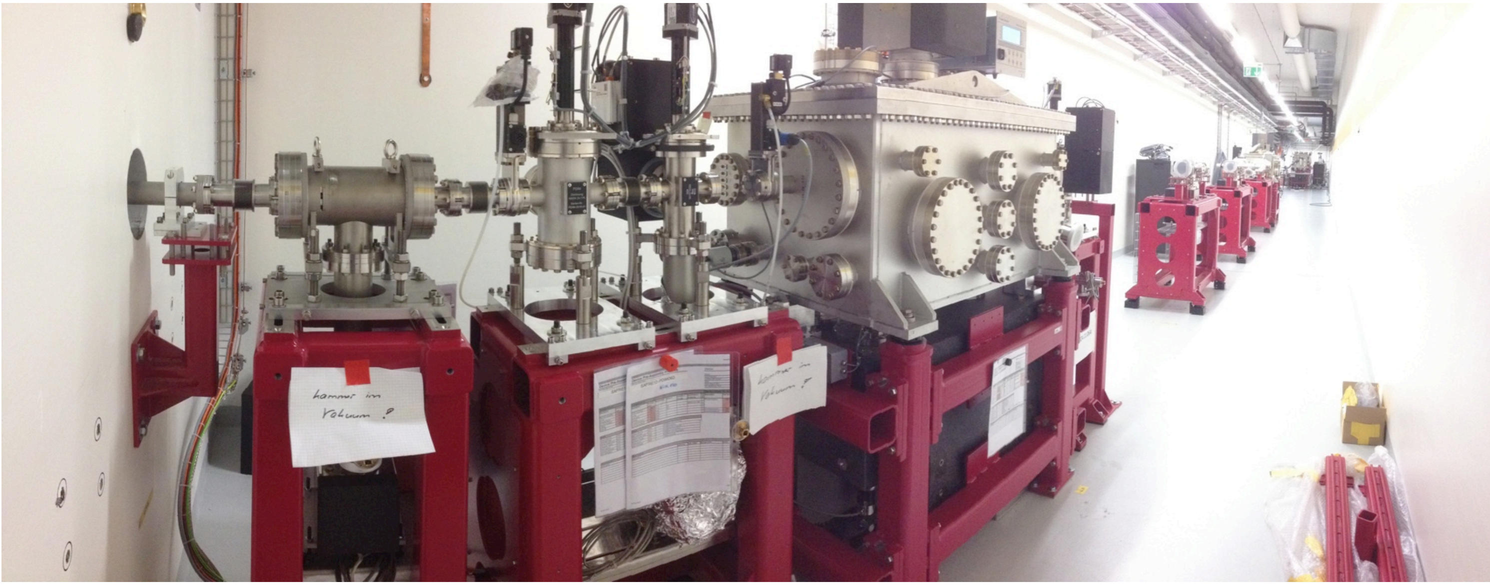
Installation: 95% completed
Cabling: 95% completed
Ready to take beam with Intensity and Position Monitors

Work in Progress

Single Shot Spectrometer: - Gratings and bendable crystal tested
(to be installed in January 2017)

Gas Monitor: -Front-end electronics (PSI) under production
delivery Jan. 2017
-Gas system: completed in January 2017

Optical hutch



Installation: 95 % completed
Cabling: 50 % completed (completed in January 2017)
HW Com.: 20% completed

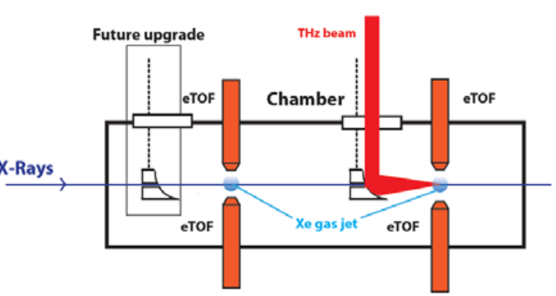
Work in Progress

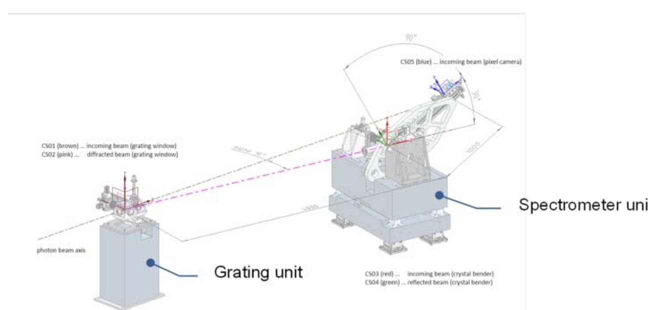
Off-set mirrors: - Vacuum chambers installed. Mirror Installation Q1 2017
DCM (RI): - FAT of 2nd DCM in Nov. 2016, installation in Dec. 2016

Photon beam diagnostics

courtesy Pavle Juranic

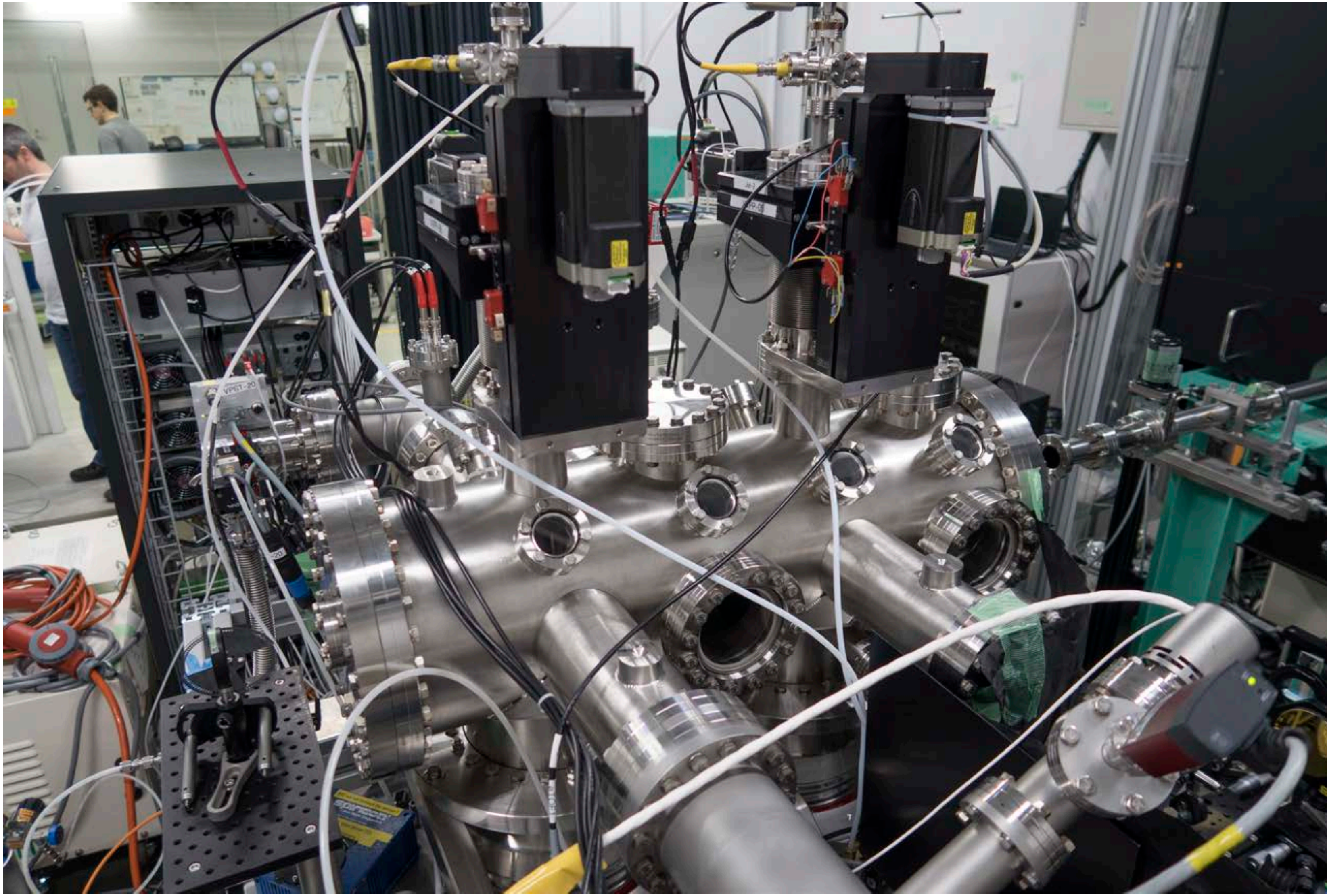
- ✔ Gas Beam Position Monitor (DESY):<10 μm
- ✔ Gas Beam Intensity Monitor (DESY): <1% relative, <10% absolute
- ✔ Beam Position Monitor: <10 μm absolute
- ✔ Profile Monitor: <10 μm absolute, 2D size
- ✔ SR Detector: <10 μm absolute, 2D size for ID commissioning
- ✔ Photo-diode Intensity Monitor: for gain curve
- ✔ Photon Single Shot Spectrometer: 10^4-10^5 resolving power, BW 0.5%
- ✔ Photon Arrival and Length Monitor: 0.5-5 fs rms
- ✔ Photon Spectral Encoding Monitor: 10-20 fs rms





- ✔ ready to be installed
- ✔ in production
- ✔ partially in production

Photon Arrival and Length Monitor



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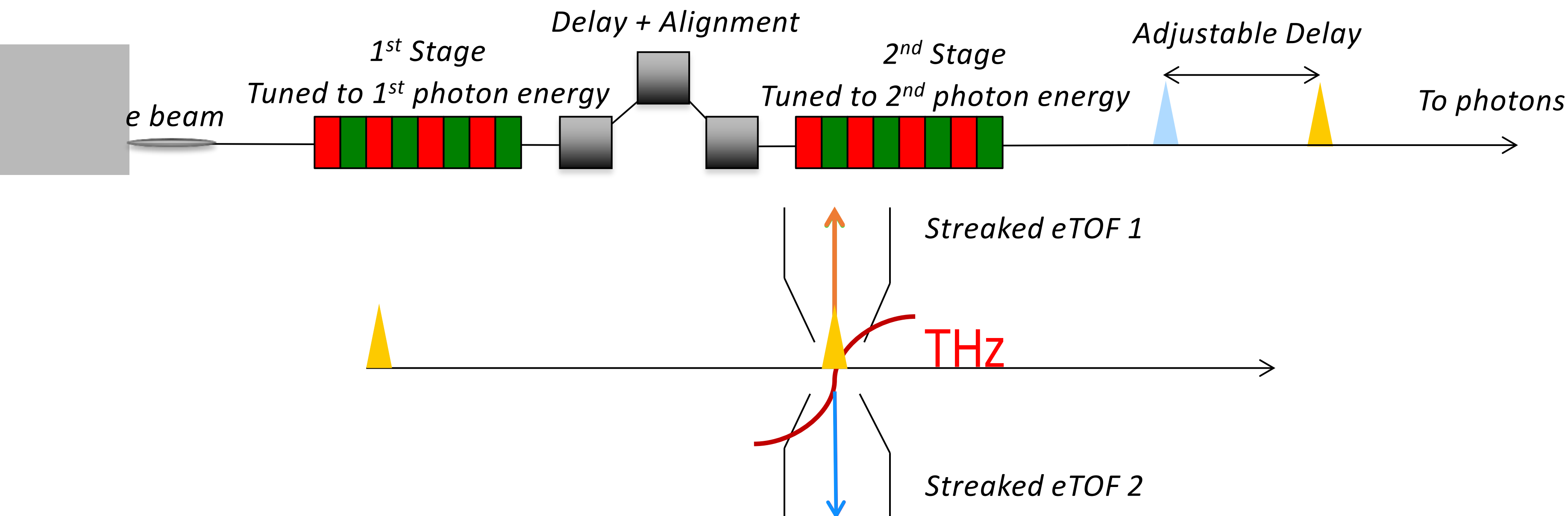
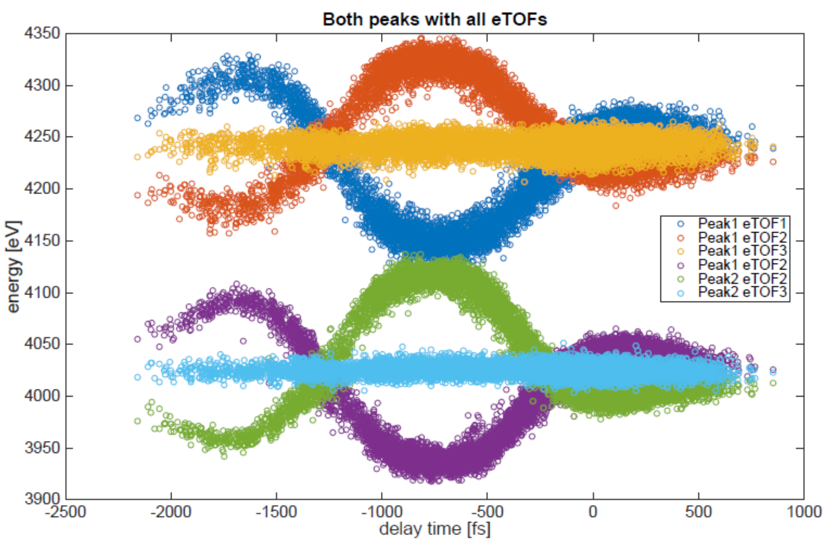
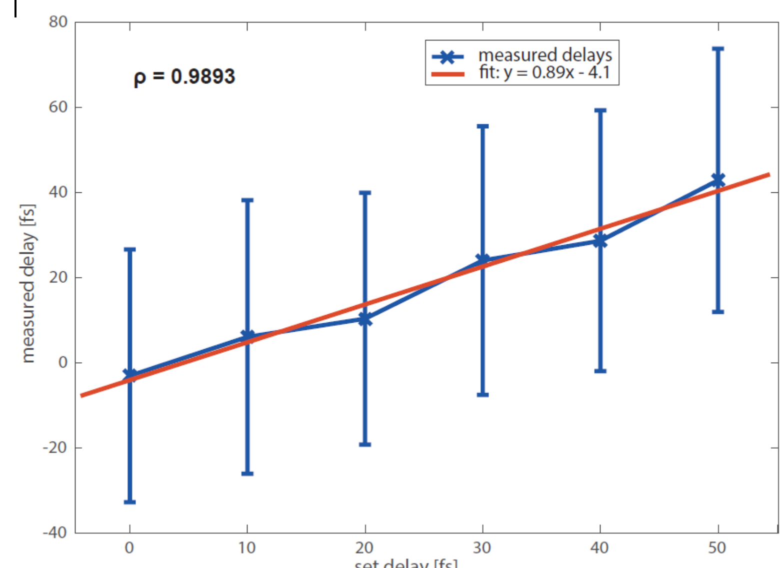
Time arrival monitor for 2-color mode

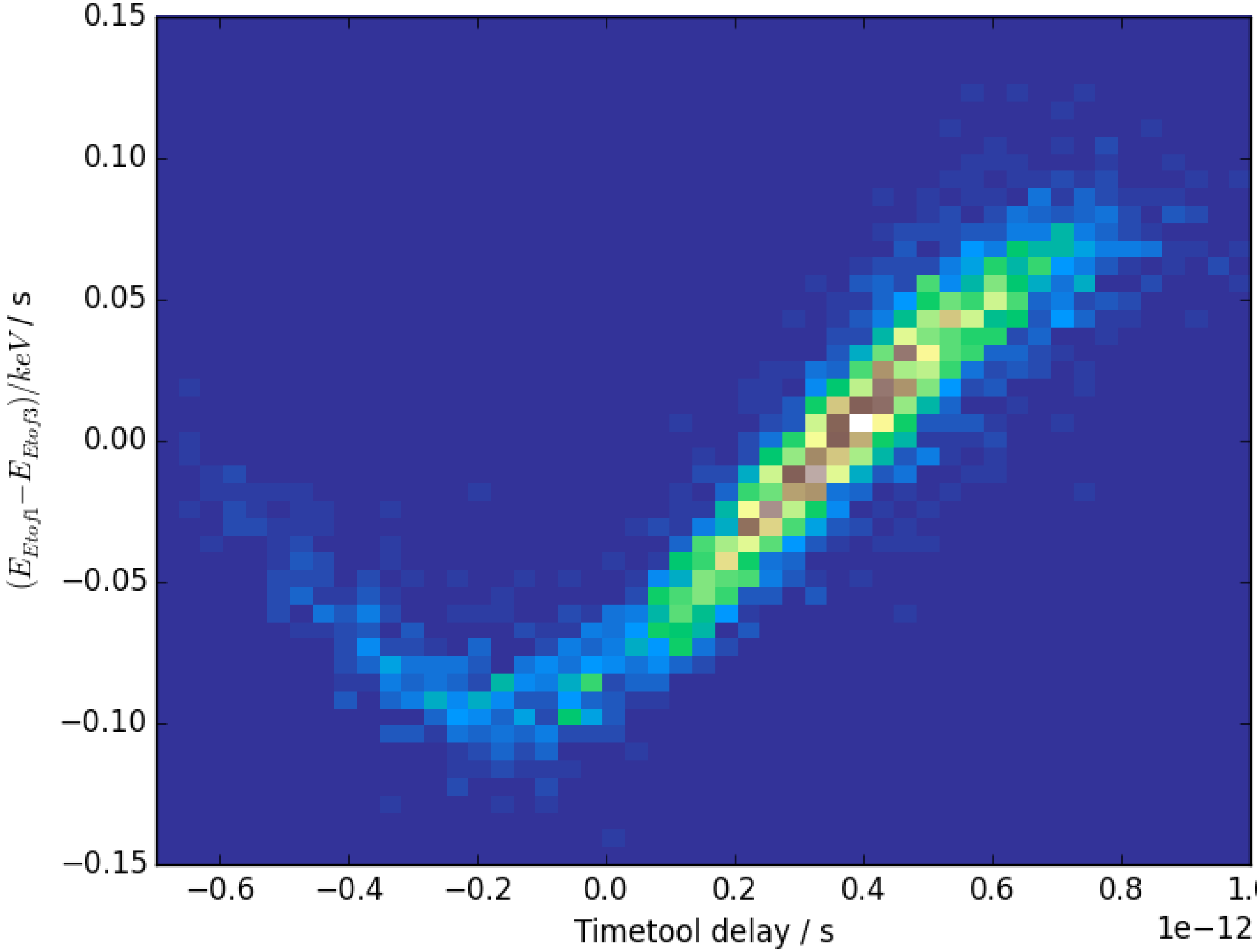
courtesy Pavle Juranic





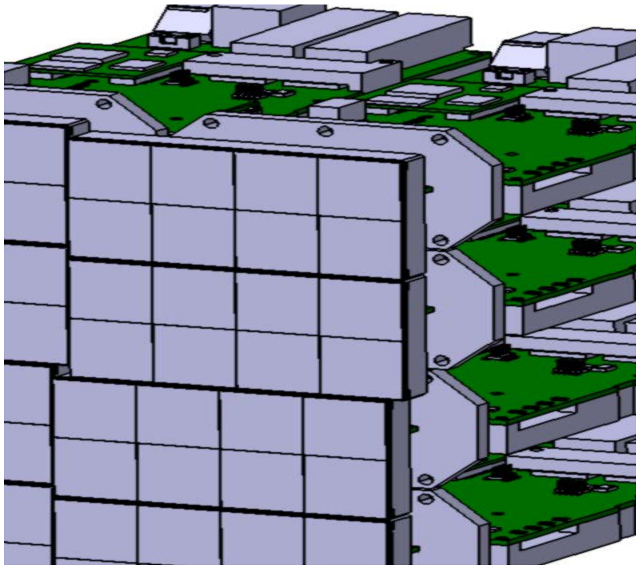


SACLA timing tool vs. PALM streak



Single Shot Spectrometer

The Jungfrau 2D detector
courtesy Aldo Mozzanica



- Specifically developed for SwissFEL applications
- Charge integrating detector with dynamic gain switching, with:
  - Front end electronics similar to AGIPD and GOTTHARD
  - Dimensions, sensor and mechanics similar to the EIGER project: 75x75 mm^2 pixel size, 4x8 cm^2 module area.

- 500k (one module), 1M (2 modules), 4M and 16M (ESA-ESB main instruments, 32 modules) systems are foreseen
- Horizontal gaps very small (8px)
- compact (20-25cm) in the Z direction
- Vacuum compatible option

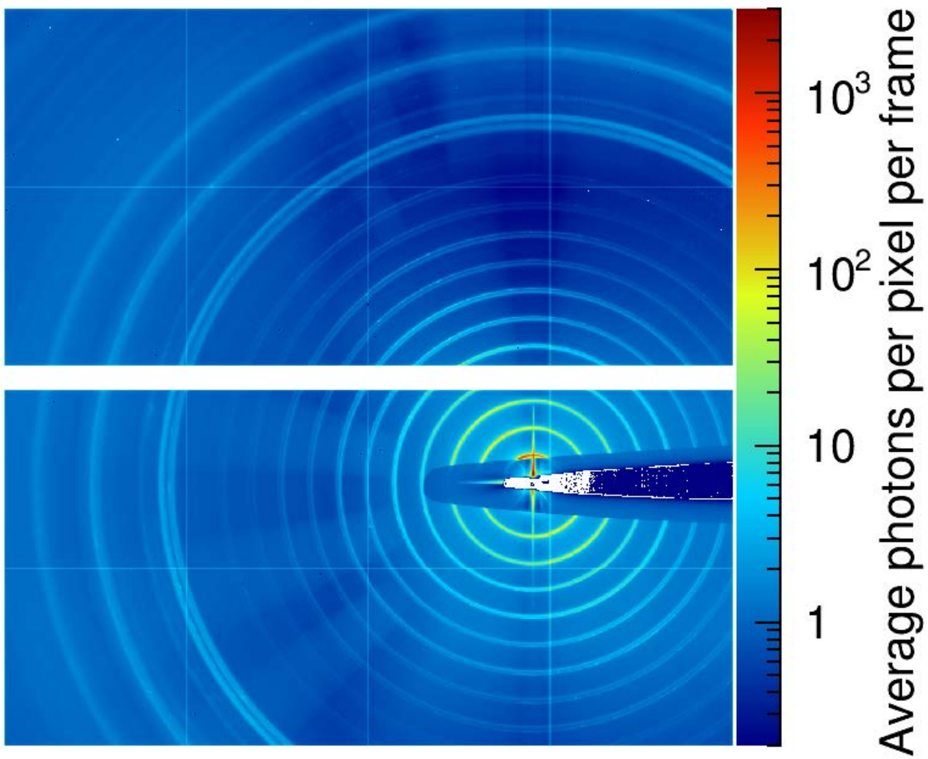
JUNGFRAU 0.1: A. Mozzanica et al., JINST, 9, C05010, 2014

JUNGFRAU 0.2: J. H. Jungmann-Smith et al., JINST, 9, P12013, 2014

JUNGFRAU Technical Design Report, J.H. Smith et al.,SwissFEL website, 2015

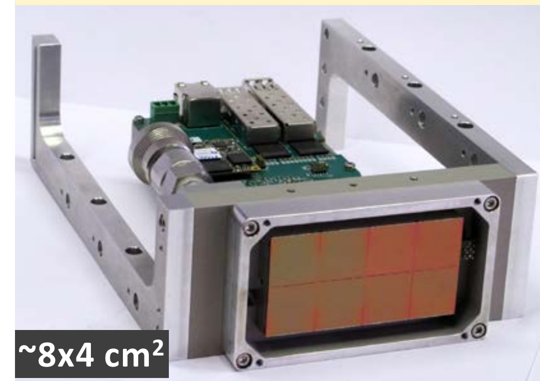
JUNGFRAU – Modules Test at LCLS

Single module:	4x2 chips = 0.5 Mpixel
Number of frames:	**~1000 Frames**
Corrections applied:	Pedestal subtraction
	Offline photon discrimination
	(5 keV equivalent threshold)

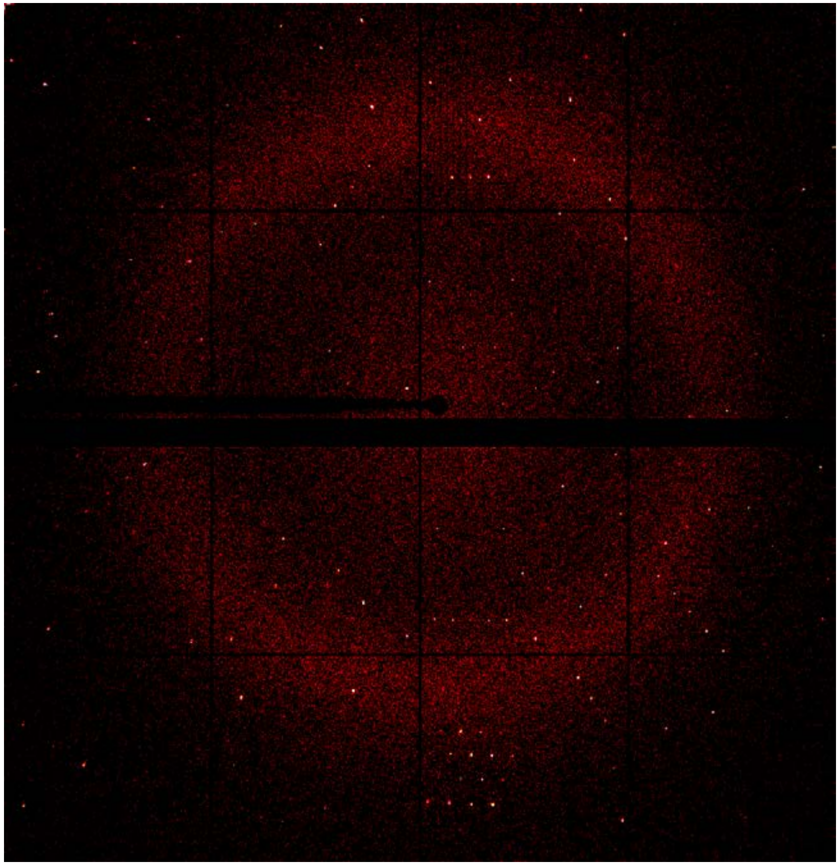


Single Module

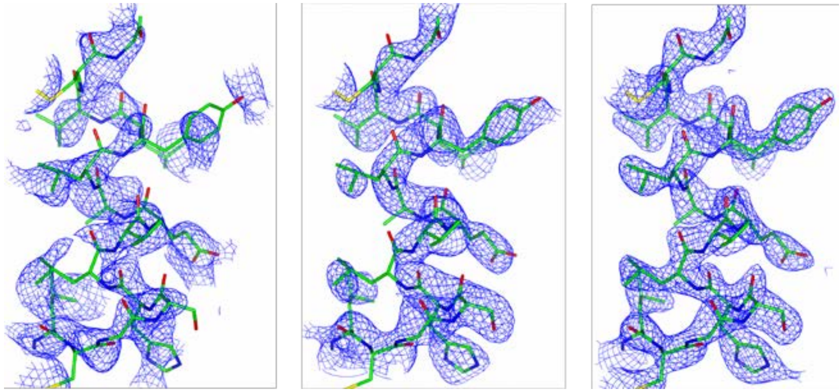
500 kPixel



First Structure solved@ SLS



Diffraction image of insulin crystal
Recorded at 6.5 keV



Electron density maps calculated from the data.
(left) After Sulfur SAD phasing with SHARP.
(middle) After solvent flattening with DM.
(right) Final map after refinement

THz requirements

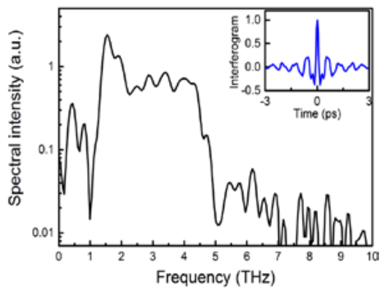
- Center frequency tunable from 0.5-18 THz
- Covers most vibrational lines, incl. (electro)magnons
- Phase stability critical (better than 10%)
- Bandwidth tunable from ~ 50% to ~5% (match material excitation)
- Ability to chirp frequency by up to 30% (Ladder climbing)
- Ability to shape polarization with time interesting, maybe not essential
- Pulse energy > 0.01-0.1 mJ

(Peak field depend strongly on spectral overlap with resonance)

THz Sources

Laser based :**Cr:forsterite pump laser**

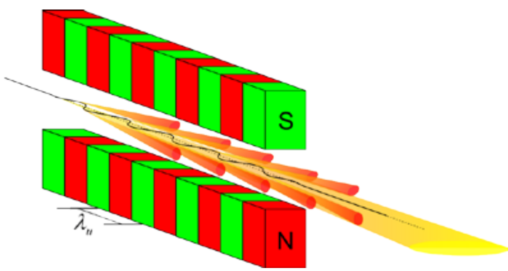
- ✓ **THz pulse energy 0.9 mJ** (1-5 THz)



C. Vicario, et. al. Opt. Lett. 2014

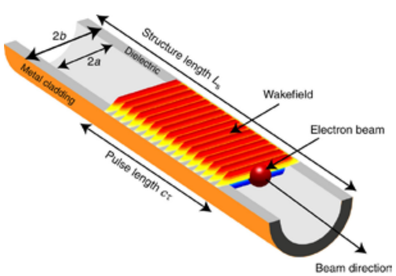
Undulator based : **new accelerator facility**

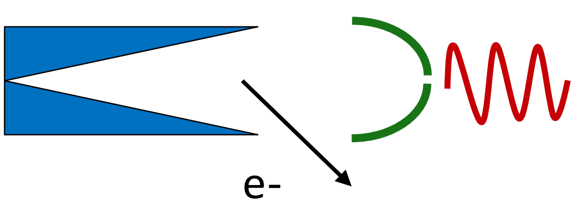
- ✓ **THz pulse energy 0.1 mJ 10 – 20 % Bandwidth**

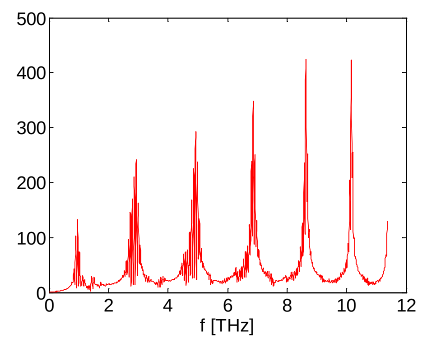


Accelerator based : **use of Wake Fields**

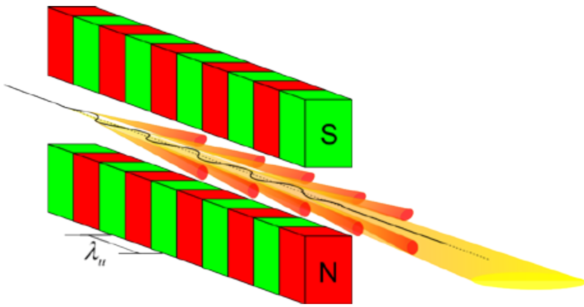
- ✓ **THz pulse energy 0.9 mJ**



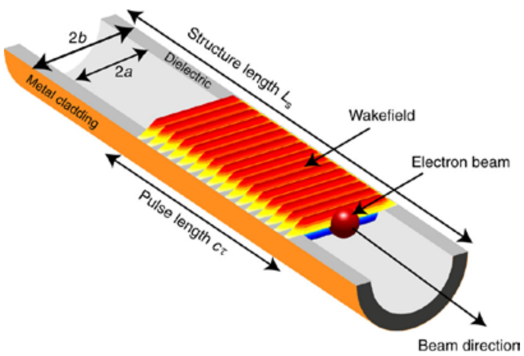




Comparison



- A completely new facility has to be built and operated:
  - Construction and operation costs
  - Several years time scale
- The undulator should be tunable for a large factor in wavelength



- Possible to use the SwissFEL beam:
  - Construction cost negligible compared to other option
  - Almost no operation cost
- Part of the extracted energy will be lost in the monochromator
- Possible synergy with ACHIP speeds up the time:
  - First tests in less than a year
  - First useful beam estimated in a couple of years

Development Plans

- **Install a scaled version of the structure in the SwissFEL injector to:**
  - Test the radiation hardness
  - Verify possible charging problem
  - Measure the radiation emitted at f<200 GHz (long bunch) using a pyroelectric detector and verify the simulation models

Agreed
(R. Ischebeck, E. Ferrari)

- **Optimize the structure:**
  - Determine the energy extracted using CST
  - Optimize the geometry of the structure in relation to the bandwidth of the radiation

Ongoing

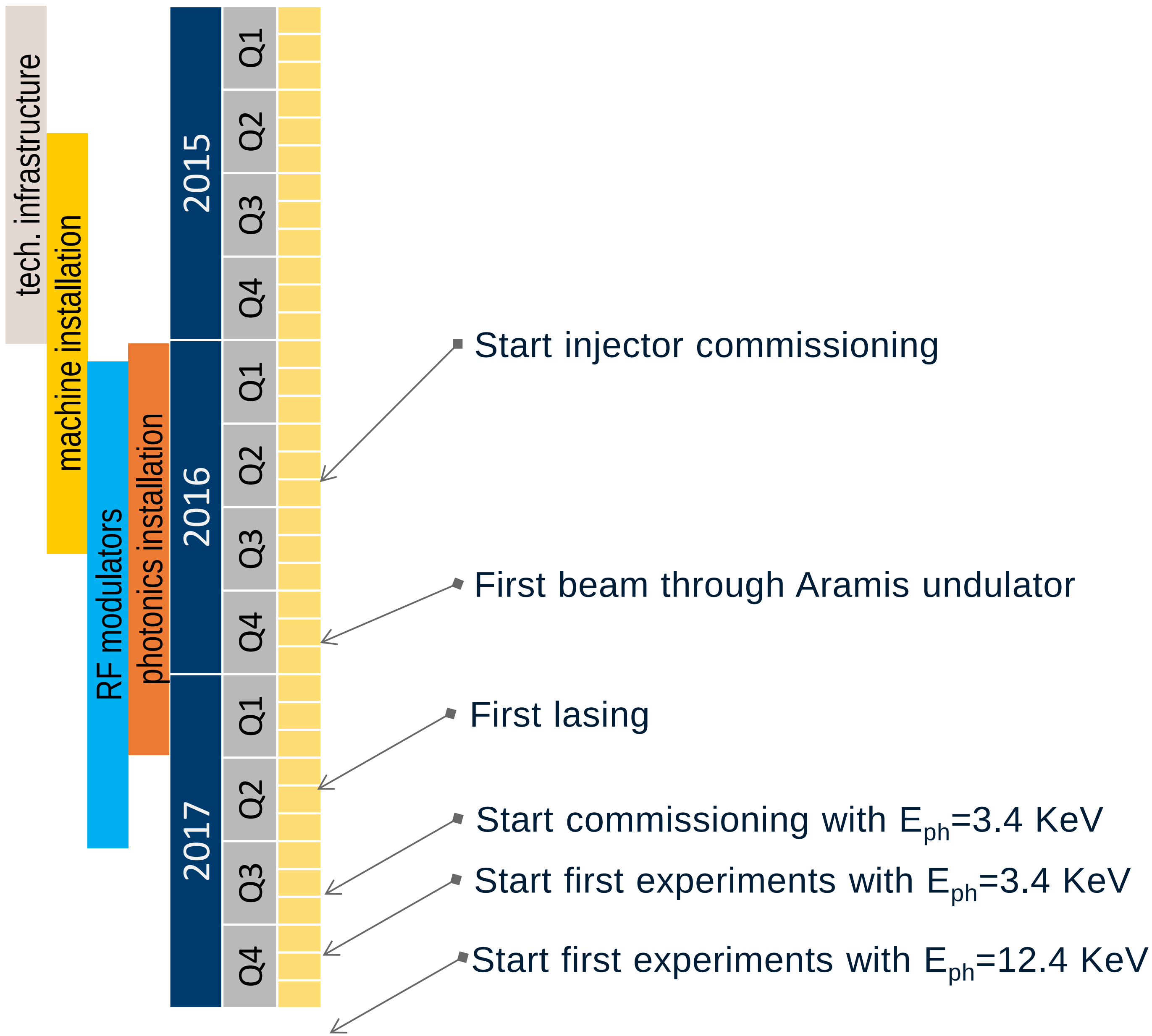
- **Determine the extraction and the transport efficiency of the THz radiation from the structure to the experimental station**

Discussions started
(R. Ischebeck, F. Frei)

- **Test at the Athos switchyard of the structure:**
  - Horizontally remotely movable structure
  - Measurement of the spectrum of the emitted radiation

Waiting for feed-back

ARAMIS Next milestones

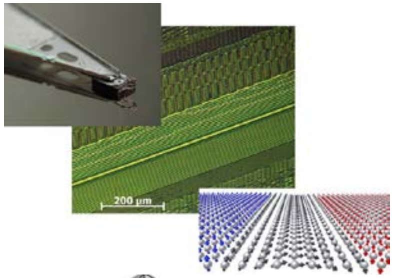


ATHOS: Science fields

SwissFEL ATHOS Science case (ed. By B. D. Patterson and M. van Daalen)

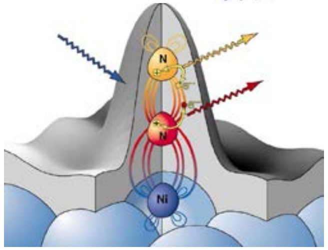
Ultrafast Magnetization Dynamics on the Nanoscale

-Temporal spin behavior in magnetic solids at short length scales



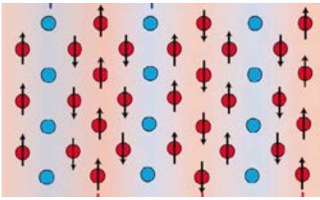
Following Catalysis and Biochemistry with Soft X-Rays

-Electronic transfer and redistribution in functional molecules



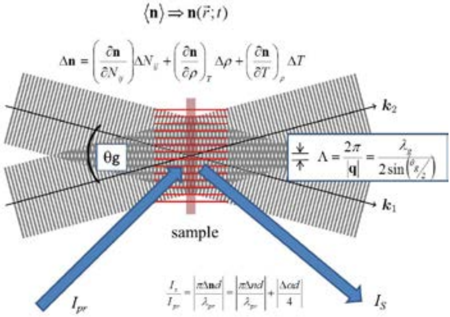
Time-Resolved Spectroscopy of Correlated Electron Materials

-Mapping the flow of energy among strongly-correlated degrees of freedom



Non-Linear X-Ray Optics

-Can the field of non-linear optics be extended to the X-ray regime?



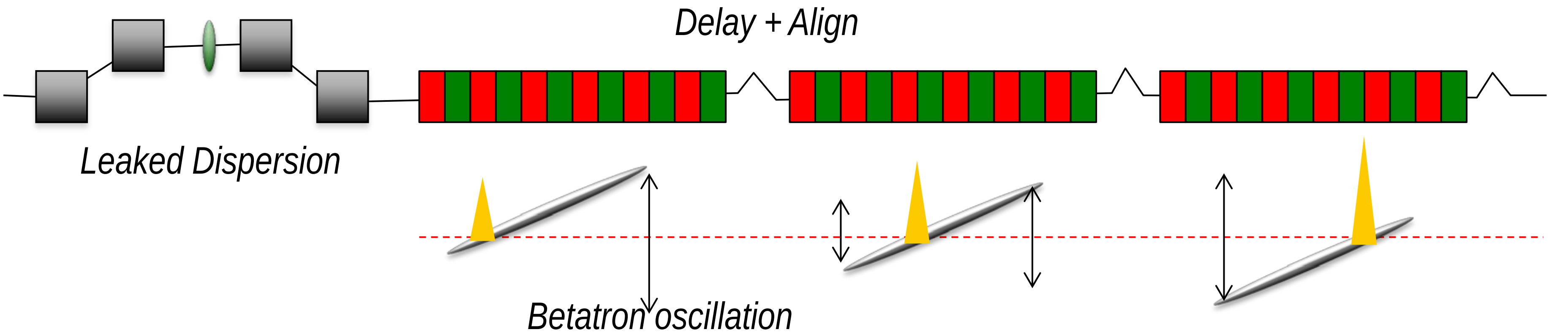
High Power Pulse Generation

courtesy Sven Reiche

[Eduard Prat and Sven Reiche PRL 114, 2448 (2015)]

[Eduard Prat, F. Löhl, S. Reiche, PRSTAB 18, 100701 (2015)]

- Inject tilted beam to only drive FEL amplification in one slice.
- Delay bunch and align bunch slice, where radiation pulse overlaps with beam.
  - Superradiant amplification by fresh bunch slice
- Delay and align multiple times to supply continuously fresh bunch parameters



Typical tilt of about 1-3 mm in the horizontal plane

This method (and the original idea) also works for:

- Any incoming tilt of the bunch
- Any energy chirp along the bunch
- Local compensation of wakefield potential

Output Pulse:

- 1.5 TW Peak Power
- 1 fs
- 1% FWHM Bandwidth
- 2 mJ Pulse Energy

Summary ATHOS operation modes

courtesy Sven Reiche

Mode	Pulse Energy	#Photons @ 1 nm	Pulse Length	Bandwidth	Comment
SASE (200pC)	>1mJ	$5 \cdot 10^{12}$	30 fs	0.1-0.4%	
SASE (10pC)	>50 μJ (10 pC)	$2.5 \cdot 10^{11}$	2 fs	0.1-0.4%	
Self-Seeding	>1mJ	$5 \cdot 10^{12}$	30 fs RMS	< 1e-4	Above 1nm, 200 pC only
Two Colors	2 x >50 μJ	2 x $2.5 \cdot 10^{11}$	2 x 2-10 fs	0.2%, tuning range: factor 5	Based on 200 pC bunch
Large Bandwidth	>0.5 mJ	$2.5 \cdot 10^{12}$	30 fs	7% FWHM	200 pC only
HHG-Seed	1 μJ (every 3 fs)	$5 \cdot 10^{9}$	< fs per pulse	0.1-0.4 %	Sub-fs locking
Slicing	1 μJ (every 3 fs)	$5 \cdot 10^{9}$	< fs per pulse	0.1-0.4 %	Sub-fs locking
Optical Klystron	As SASE	$5 \cdot 10^{12}$	As SASE	As SASE	More length for taper
TW Pulse	> 1mJ	$5 \cdot 10^{12}$	1 fs	1% FWHM	200 pC bunch
HB-SASE	As SASE	$5 \cdot 10^{12}$	As SASE	0.02-0.04%	Can also be configured for pulse trains

Considerations

The first years of user operation at SwissFEL are built up regarding following issues:

- Improving the performance of ARAMIS accelerator, beamlines and stations
- Installation and commissioning of ATHOS
- Building up experienced staff

Beamtime dedicated for „FEL production“ will be split up :

▪ Users time	70%
▪ Exp station commissioning and in-house research	25%
▪ Discretional „directors time“	5%

Scheduling 2018/2019

The general yearly schedule is coordinated with all large scale facilities at PSI HIPA, SINQ, SLS to avoid peak load of the staff responsible to maintain and run.

Start of SwissFEL operation:	second week of January
Shut downs:	Two weeks in April/May
	Five weeks in August
End of Operation	Third week in December

Beamtime will be distributed in blocks of 4 weeks:

ESA	ESB	Accelerator	Installation

The week dedicated to experiments will be distributed in
1 day setting up; 5 days for experiment, 1 day installation

User Operation 2018

Start of regular Users Operation	May 2018
Call for proposals	September 2017

OPERATION Mode : 5.8 GeV, 200 pC, 30 fs

All diagnostic in Front End and Optics ready

Timing tools : THz Streaking and Spectral Encoding ready

Two Experimental Stations commisioned:

ESA: Prime and FLEX

ESB: General Purpose System and Diffractometer

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Wir schaffen Wissen – heute für morgen

My thanks go to

- Photonics Team
- Technicians NUM
- Technicians SYN
- Engineers LOG
- Controls/Vacuum GFA