Accelerator Update

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For the European XFEL operations team

European XFEL Users Meeting
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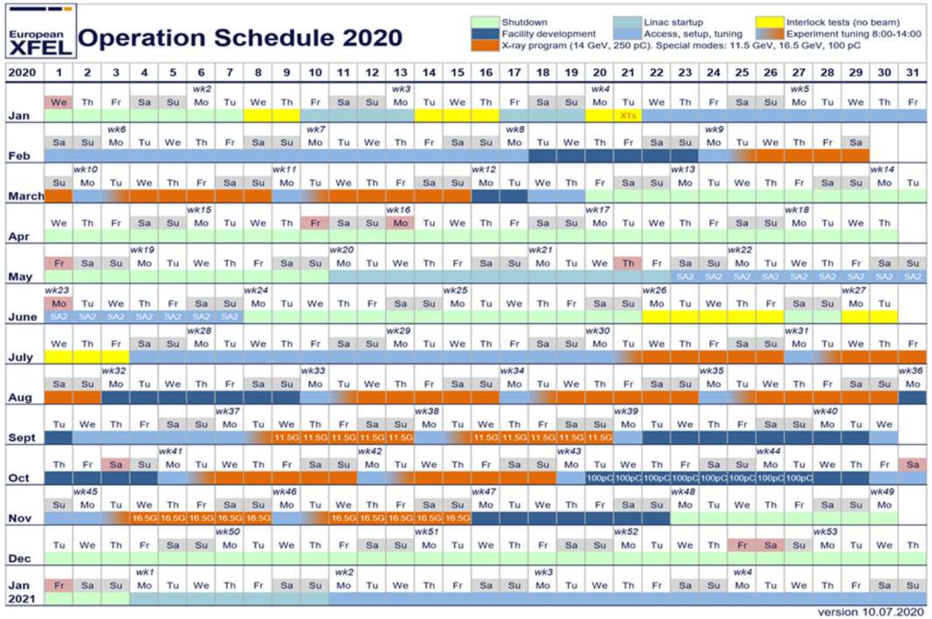
2020 – forget it ?

- COVID-19 caused ‘deep’ shut-down of about 8 weeks beginning of 2020

Definitely not

- Three linac start-ups helped to further mature linac operations
- Extended study times for FEL tuning and stability greatly improved operations
- Back to safe routine operation since summer 2020 with about 1700 hours of scheduled photon delivery for experiment commissioning, in-house research, and user service

	Planned 01/2020	Adjusted 03/2020	Executed
Scheduled down	1896 hours	3144 hours	
Set-up, tuning, unscheduled access	2568 hours	2856 hours	
Facility development (accelerator & photon systems)	1176 hours	1104 hours	
Photon delivery	3144 hours	1680 hours	1680 hours



Linear accelerator operation matured

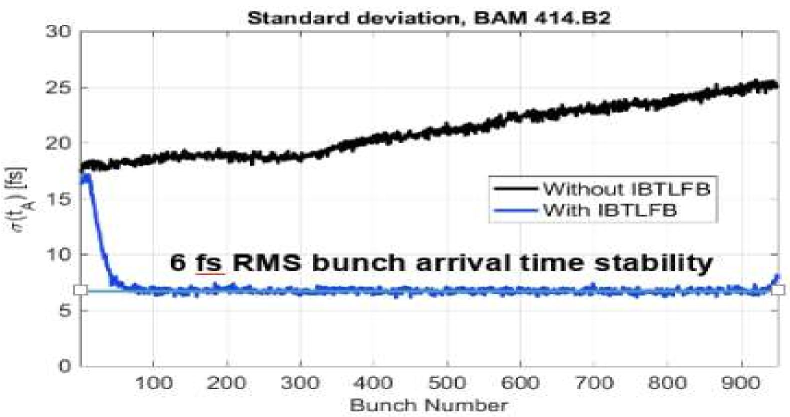
Three Linac Start-Ups in 2020 – getting better every time

- 01/02 2020
  - New LLRF server
  - Full piezo commissioning and operation
  - Re-established 17.6 GeV & improved stability
- 05 2020
  - Re-start out of de-tuned state
  - Refined handling and calibration scripts, lessons learned from 01/02 2020
- 07 2020
  - Establish low (for operation up to 14 GeV) and high (for > 14 GeV) linac working point
  - Refined fault analysis, now 'fully' automated

Linac Stability

- Modules for LLRF stabilization fully deployed in 2020
  - **REFMOPT**: re-sync of RF reference to stabilized optical links => stabilization of drifts due to environmental changes
  - **D**rift**C**ompensation**M**odule compensates for drifts within local LLRF system
- Excellent shot-to-shot and long term stability
- And can be improved with Intra Bunch Train Longitudinal Feedback

Impact on experiments:
Studied in dedicated measurement campaign
in framework of stability task force

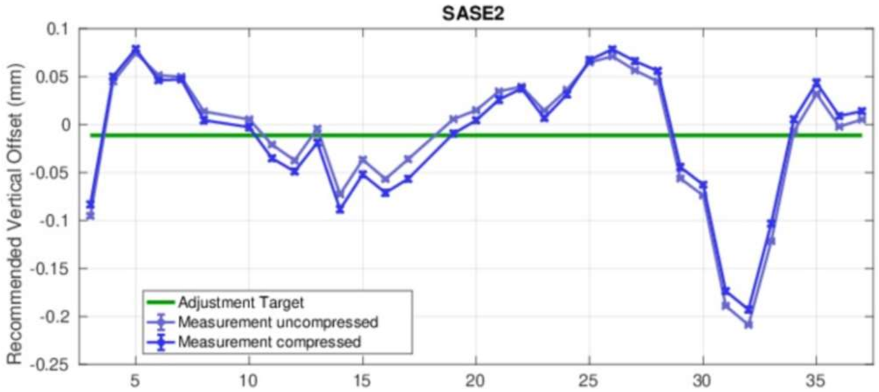


Standard FEL Tuning Procedure Established

Benefited from 1.5 week study time before summer shut-down and availability of diagnostics and procedures

After Shut-Downs (twice per year)

1) Beam Based Alignment
2) Adjust Undulator mid-plain to BBA Orbit using (K-Mono)

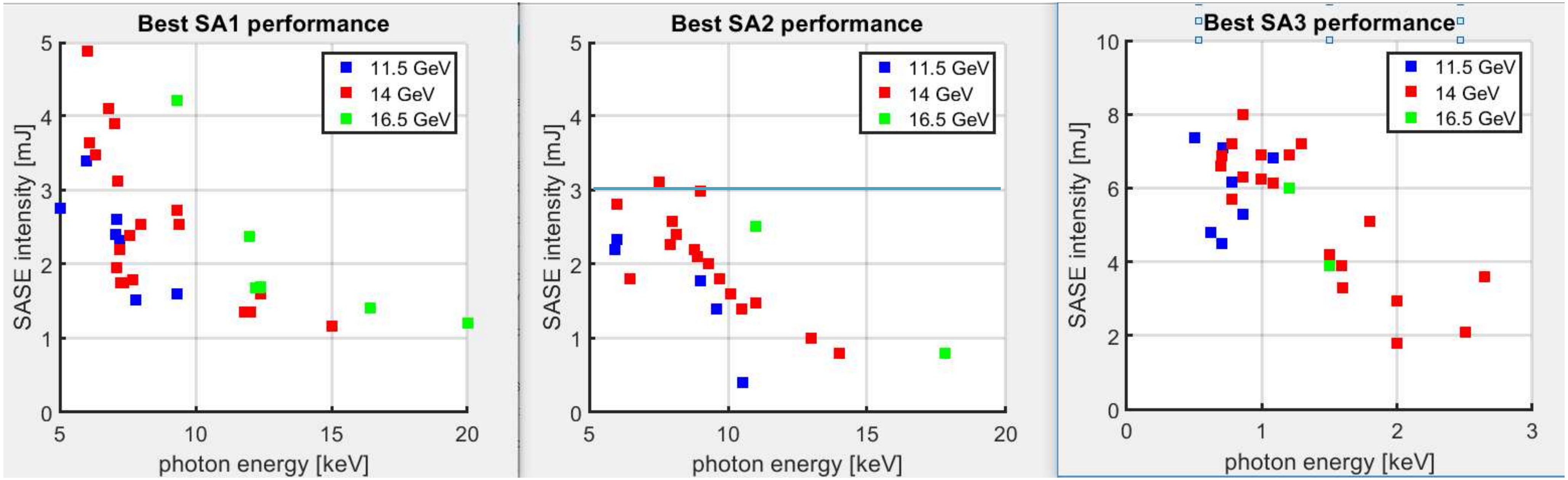


3) Measure and Correct Undulator K-Offsets (K-Mono)
4) Measure and apply Wakefield compensating linear taper

Each delivery run (weekly)

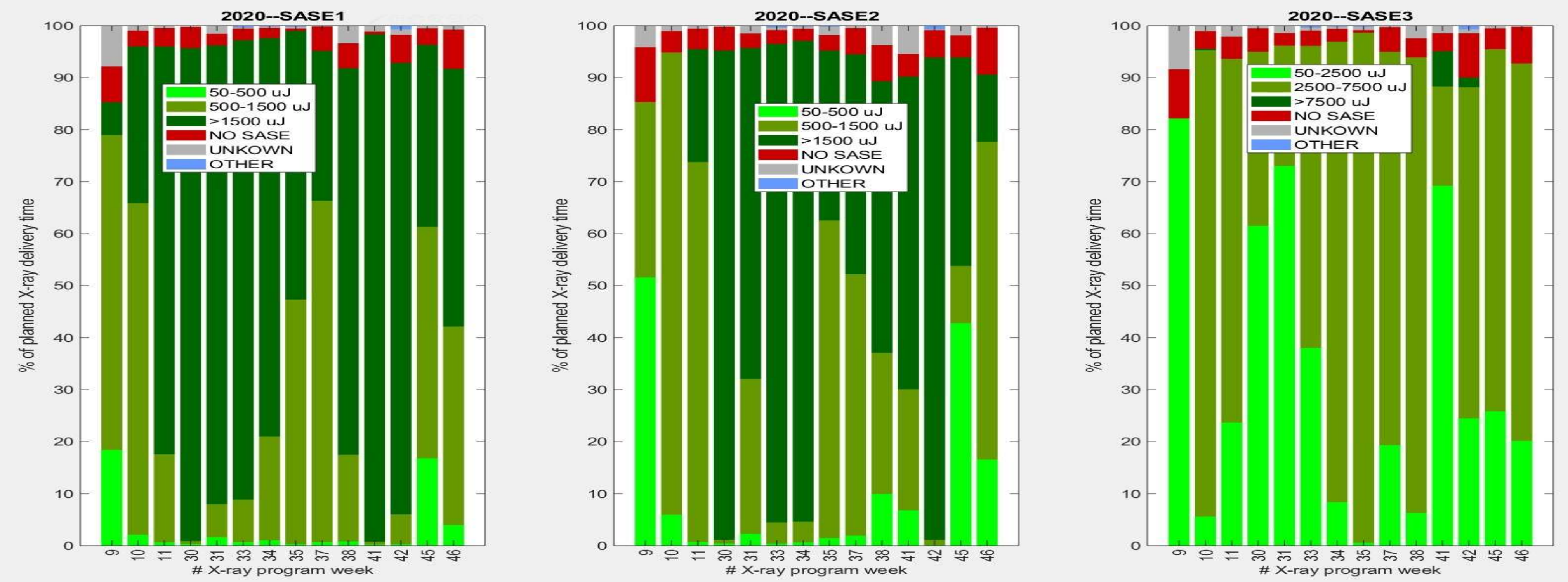
1) Optimize Accelerator: Emittance, Dispersion, Compression, Orbit, Matching, Laser Heater
2) Establish initial SASE level
3) Fine tune linear taper in gain regime and optimize quadratic taper by maximizing power
4) Empirical fine tuning (for power) at each undulator gap setting, wavelength tune-ability suffers but intensity gains
5) Adjust pointing

SASE Performance greatly improved



- SA1/SA2 on equal intensity
- Peak performance limited by safety considerations
- Remaining challenge (for both hard X-ray undulators) is fast photon energy scaling

SASE Availability 2020 about 95%



Purely intensity measurement based statistics

SASE Performance Greatly Improved

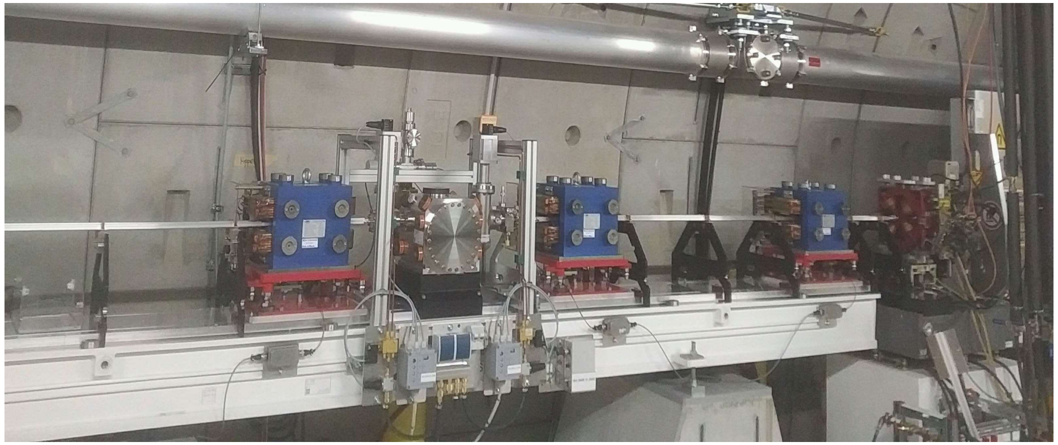
- Intensity expectation values increased

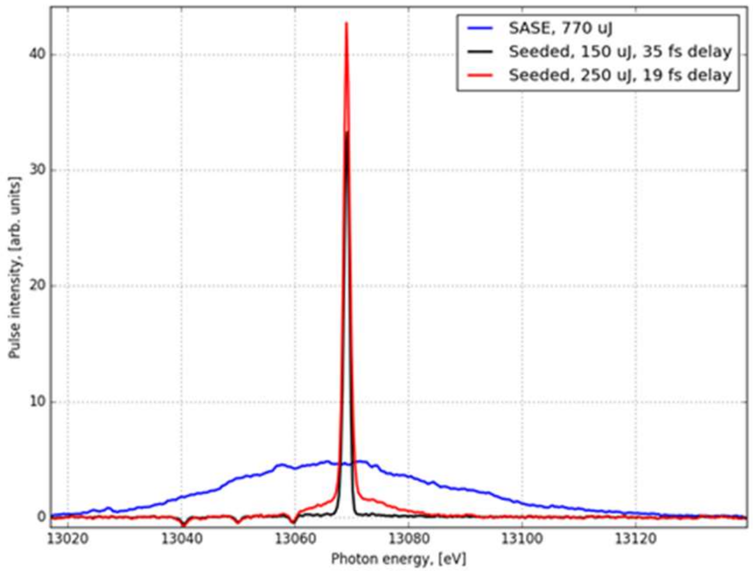
		Till 2020	2021
SA1	5-9.3 keV	1 mJ +/- 50%	2 mJ +/- 20%
	>9.3-14 keV	1 mJ +/- 50%	1 mJ +/- 20%
	>14 – 20 keV	not defined	0.5 mJ +/- 20%
SA2	5.8-9.3 keV	1 mJ +/- 50%	2 mJ +/- 20%
	>9.3-12 keV	1 mJ +/- 50%	1 mJ +/- 20%
	>12 – 18 keV	not defined	0.5 mJ +/- 20%
SA3	0.5-1.5 keV	5 mJ +/- 50%	5 mJ +/- 20%
	>1.5-2.5 keV	5 mJ +/- 50%	2 mJ +/- 20%

- But: for a detailed description of risks and adverse effects apply consult your local contact.

New Developments: Hard X-Ray Self Seeding @ SASE2

- Generate and amplify an initially weak seed photon pulse, enhancing longitudinal coherence and narrowing the spectra
- First commissioning in 2019
- Up to 800 µJ within 0.7 eV FWHM bandwith at 9 keV achieved
- Demonstration of multi-bunch (4000/second) capability)
- Ready for initial delivery to experiments, several proposals in Q1 2021 had incorporated this capability

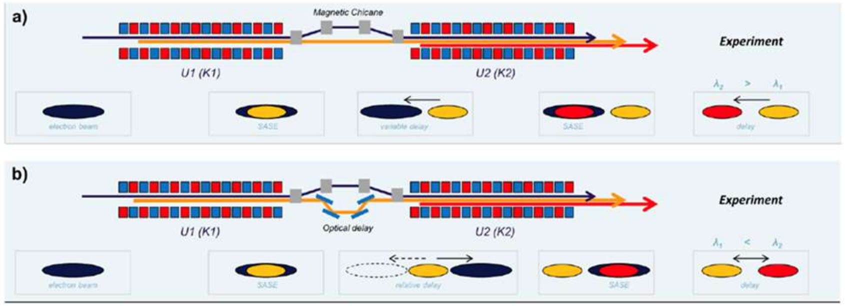


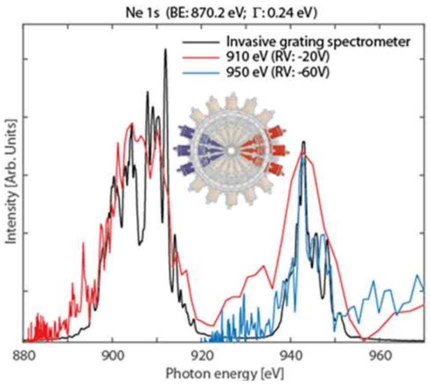


Average self-seeding spectra at 13 keV: nominal SASE operation (blue), setup which was optimized for spectral purity (black), setup which maximizes the spectral flux (red)

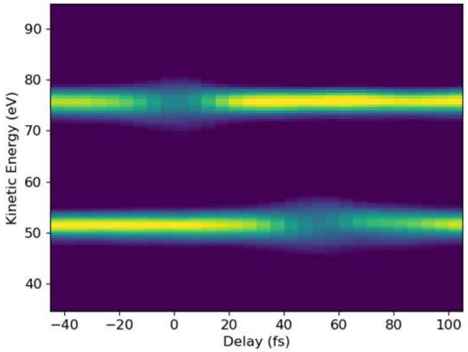
New Developments: 2 Colour Pump Probe @ SASE3

- Create 2 colour FEL in separate parts of undulator with and delay electron bunch in magnetic chicane
- Controls, tuning, and photon diagnostics





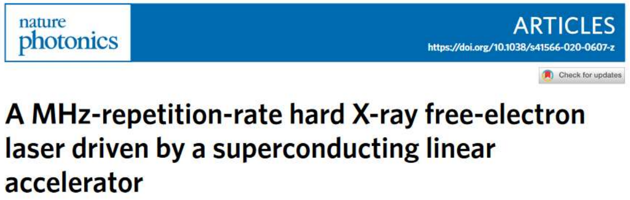
Single shot electron spectra of Neon measured with grating spectrometer (black line), with PES optimized for 910eV and 950eV emitted in one of the two undulator sections



Electron spectra for C1s ionization of CH_3F at 662 and 688 eV, X-ray pulses separated in time by 50fs visualized by perturbation in the electron spectra due to overlap with optical laser pulse.

European XFEL Accelerator Update - Summary

- In operation since 2017, service to all 6 experiments since beginning of 2019
- Superconducting linac operation matured, all design parameters achieved
  - Maximum energy 17.5 (typical 11.5/14/16.5) GeV
  - Maximum 27000 (typical 13500) electron bunches/second in 10 Hz burst mode, only small fraction (<20 %) used for photon production
  - Very flexible beam distribution into 3 beamlines with up to 4.5 (typical 2.25) MHz switching frequency and arbitrary bunch patterns
- Three FELs in parallel operation
  - Soft X-Ray (SASE 3) : 0.5 – 2.8 keV, up to 8 mJ/photon pulse
  - Hard X-Ray (SASE1/2): 5 – 20 keV, up to 4 mJ/photon pulse
  - 30 keV demonstrated
- Advances in FEL scope extension
  - Hard X-ray self-seeding @ SASE2 ready for first test experiments
  - Two-color operation @ SASE3 including pulse delay using new magnetic chicane
- COVID-19 caused ‘deep’ shut-down of about 8 weeks beginning of 2020 and continues to wreak havoc with our plans


nature photonics ARTICLES
https://doi.org/10.1038/s41566-020-0607-z
Check for updates

A MHz-repetition-rate hard X-ray free-electron laser driven by a superconducting linear accelerator

(Accelerator) Parameter Space (as of Today)

Quantity	Unit	Project Goal	Achieved	Routine
electron energy	GeV	8 – 17.5	6 – 17.5	14
bunch repetition within pulse	MHz	Up to 4.5	Up to 4.5	2.25
bunch charge	pC	20 – 1000	100 – 500	250
max. beam power	kW	500 kW	80 kW	40 kW
undulators in operation (lasing)		SASE1-3	SASE1-3	SASE1-3
photon pulses / s / undulator		27000	5000	4000
photon energy	keV	0.25-25	0.4-4.5; 5.8-30	0.6-2.2; 6 – 14
photon pulse intensity (SASE1) @ 14 GeV, 250 pC, 9.3 keV	mJ		4	2
photon pulse intensity (SASE3) @ 14 GeV, 250 pC, 600 – 900 eV	mJ		10	>5
photon pulse intensity SASE2 (@ 14 GeV, 250 pC, 9 keV	mJ		3	2