Experience with long undulator operation at European XFEL

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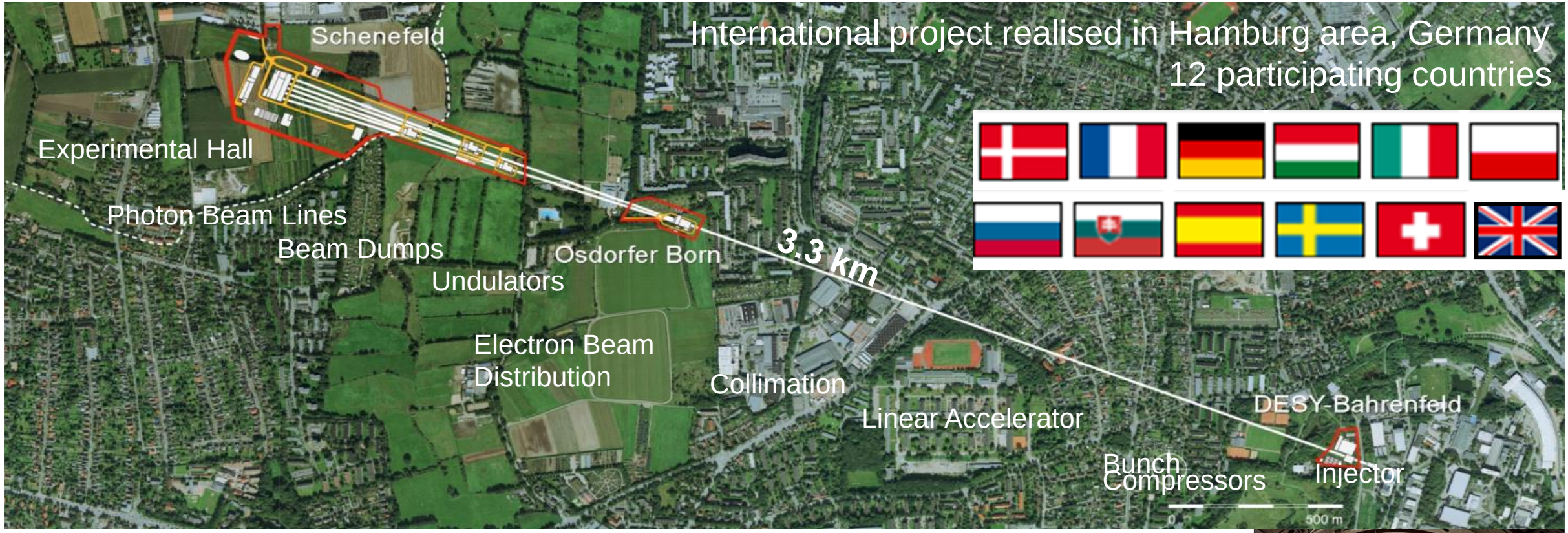
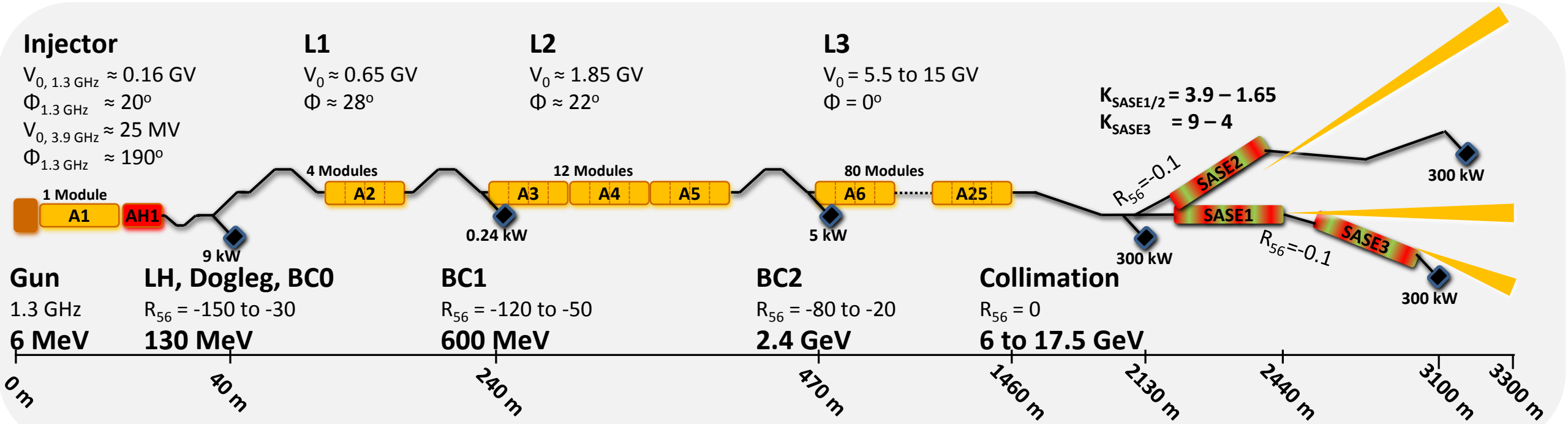
European XFEL at a Glance



- 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
- In operation since 2017, service to all 6 experiments since beginning of 2019

Accelerator Overview



- Superconducting linac with 97 1.3 GHz superconducting modules and 17.5 GeV max. energy
- 10 Hz pulsed mode with 600 µs flat-top, 2700 bunches/pulse, about 500 kW max. beam power
- Variation of bunch charges between 20-1000 pC foreseen to vary final pulse length
- Fast distribution of bunches into beam distribution lines

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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Undulators

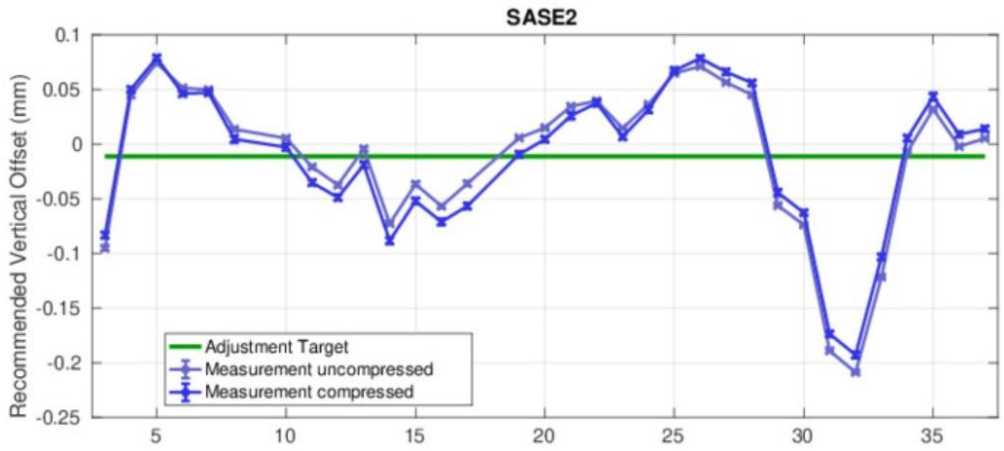
	SASE 1/2	SASE3	ILC
Type	PM Planar		SC Helical
Lattice	12.2 m FODO		30 m FODO
Period Length [mm]	40	68	11
Full Vacuum Gap [mm]	8	8	5 (?)
K Range	4 – 1.65	9 – 4	0.9
B [T]	1	1.4	1 (?)
Effective Length	175	105	231
E loss from ISR @ max Energy	20 MeV	20 MeV	2 GeV (?)

Undulator Operation: Standard FEL Tuning Procedure

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)



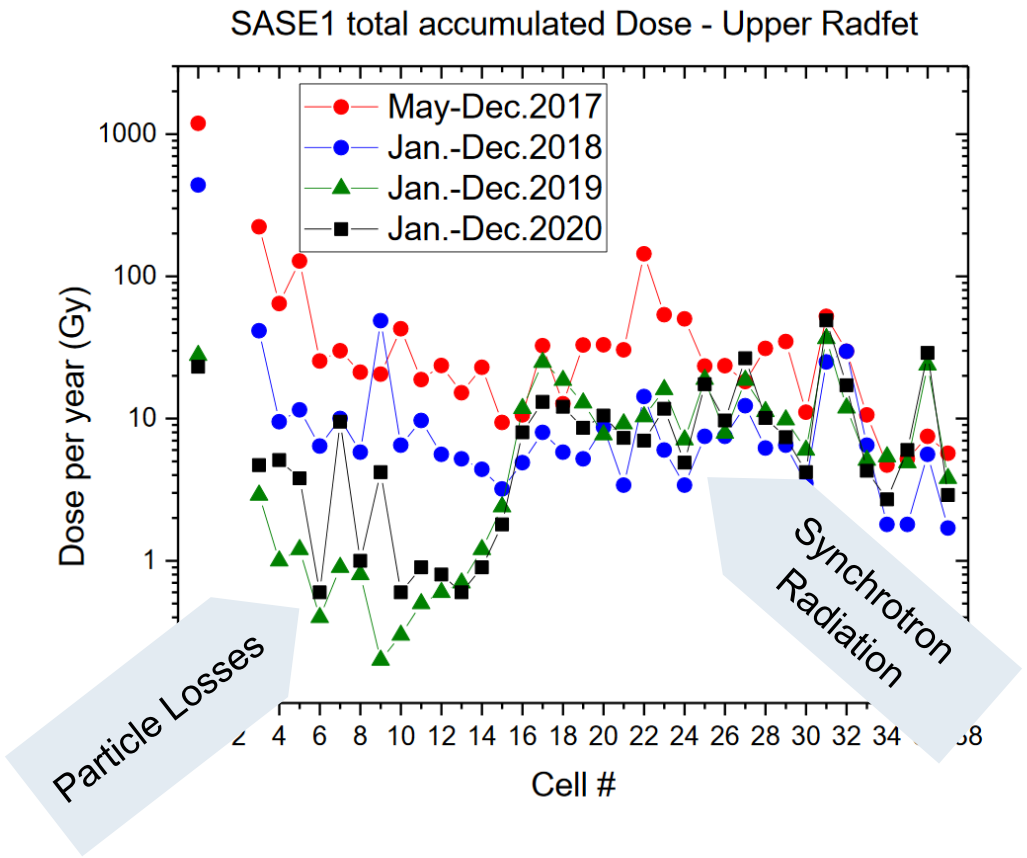
3) Measure and Correct Undulator K-Offsets (K-Mono)
4) Measure and apply Wakefield compensating linear taper

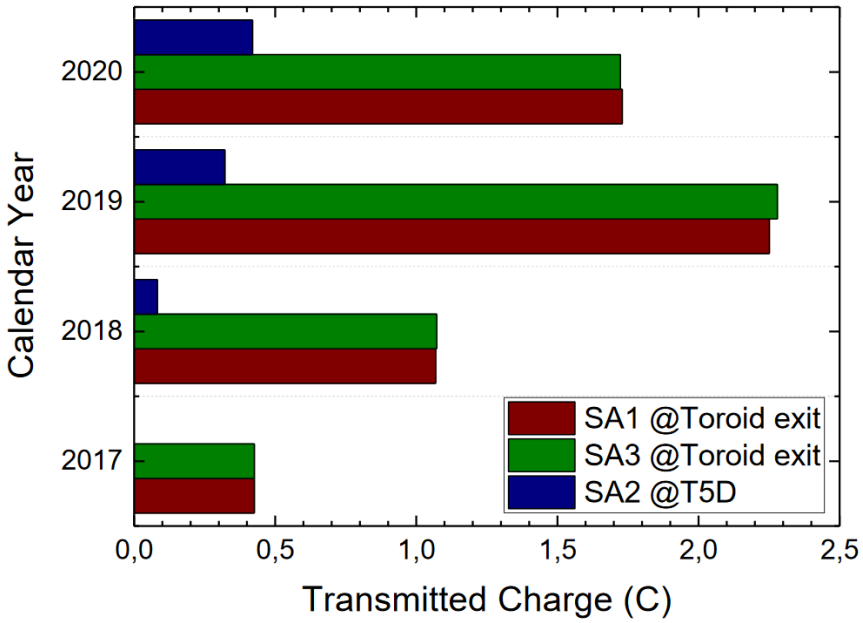
Each delivery run (weekly)

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

Losses

Dominated by synchrotron radiation
Particle losses account for a few Gy/year
PM damage (1e-4 field drop) expected at about 200 Gy





Total Charge accelerated by linac 57 C !!

Summary

- XFEL operates 91 permanent magnet undulators of 5 m length each, embedded into a 12.2 long FODO cell with an average beta function of 30 m.
- The inner vacuum gap is 8 mm. The upstream collimation system can protect a gap down to 5 mm. The maximum beam power in the undulator can be up to 300 kW, 40 kW are demonstrated.
- Energy losses in the undulator due to particle loss are minimal (cannot be measured), except for sporadic missteering events when hardware fails. No radiation damage (= field change > 2e-4) to the undulators has occurred after 3 years of operation.
- Beam is aligned with beam based methods to about 10-20 micron accuracy on a straight line of about 200 m (=undulator length) length, remeasured every 6 month yielding max 100 micron deviation
- During beam operation trajectory is controlled better 3 micron with slow and fast beam feedback systems

- More info & tests: come and ask or propose measurements

(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

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