Generation of Sub-fs X-Ray Pulses at the European XFEL

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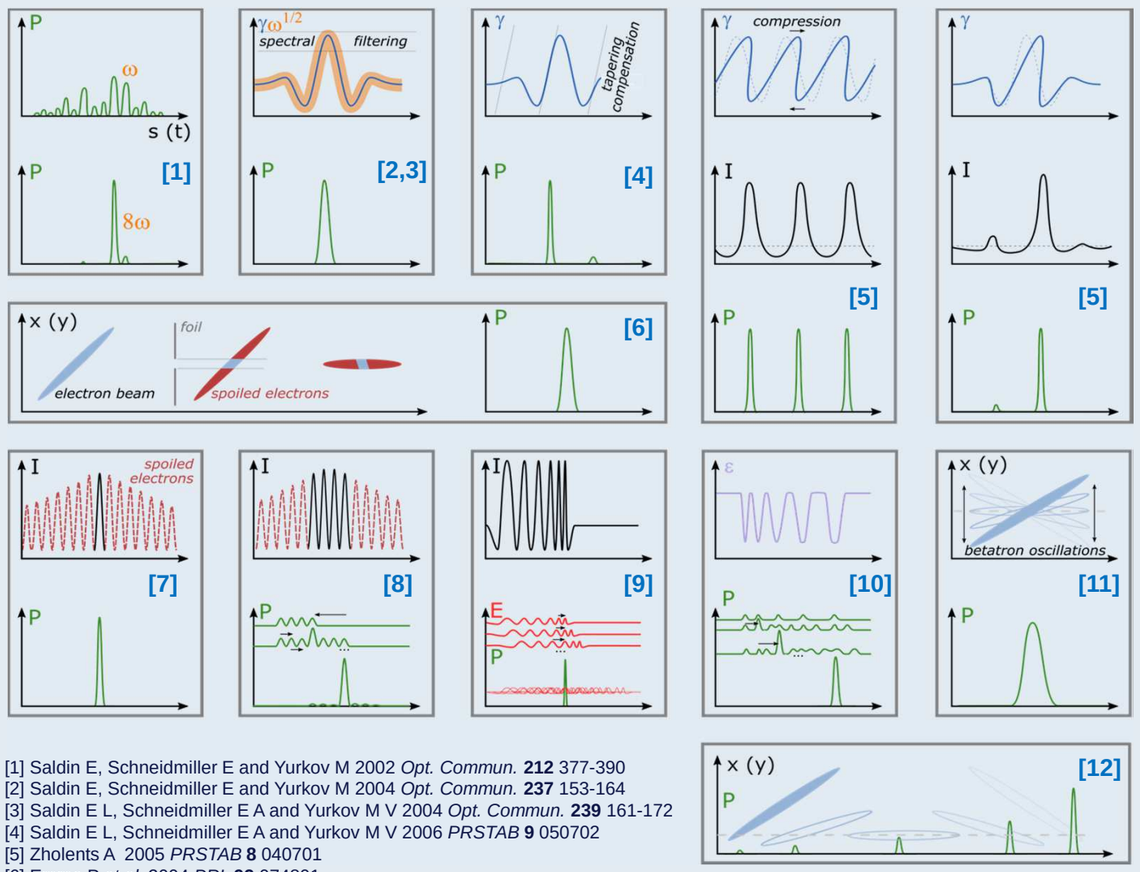
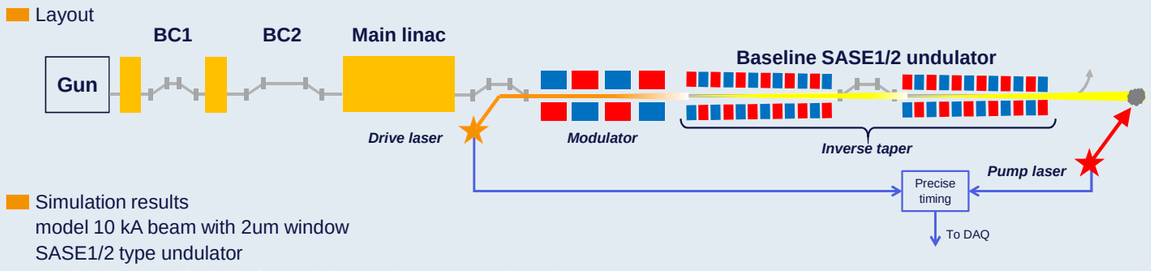
Attosecond FEL methods



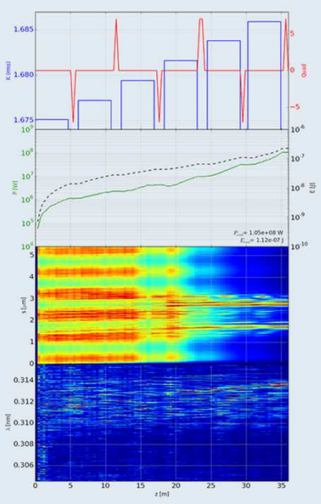
[1] Saldin E, Schneidmiller E and Yurkov M 2002 *Opt. Commun.* **212** 377-390
[2] Saldin E, Schneidmiller E and Yurkov M 2004 *Opt. Commun.* **237** 153-164
[3] Saldin E L, Schneidmiller E A and Yurkov M V 2004 *Opt. Commun.* **239** 161-172
[4] Saldin E L, Schneidmiller E A and Yurkov M V 2006 *PRSTAB* **9** 050702
[5] Zholents A 2005 *PRSTAB* **8** 040701
[6] Emma P *et al.* 2004 *PRL* **92** 074801
[7] Macarthur J P et al. 2017 *Proc. IPAC17* 19-21
[8] Tanaka T 2013 *PRL* **110** 1-5
[9] Tanaka T 2015 PRL 114 044801
[10] Prat E and Reiche S 2015 PRL 114 244801
[12] Prat E, Lohl F and Reiche S 2015 PRSTAB 18 100701
[11] Emma P and Huang Z 2004 NIMA 528 458-462

[4]+[6]: Energy modulation + Inverse taper

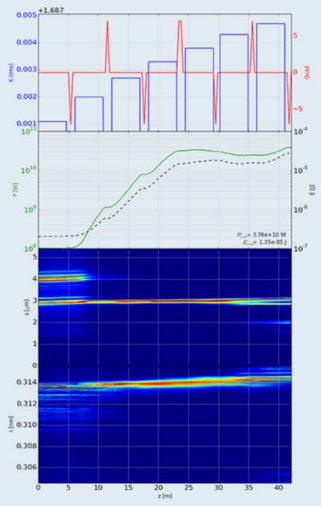
Layout



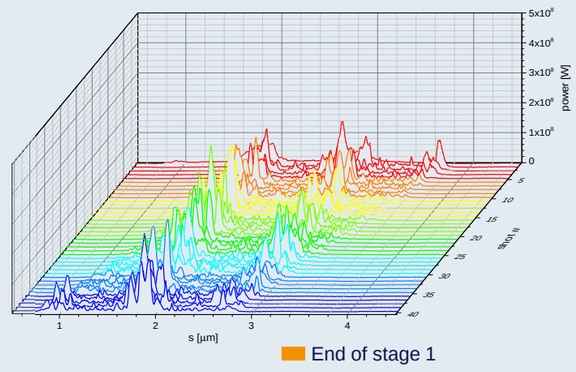
Simulation results
model 10 kA beam with 2um window
SASE1/2 type undulator
8.5 GeV beam, 30 MeV p2v modulation with 1um wavelength
4KeV: 400 as fwhm with 10^{10} photons



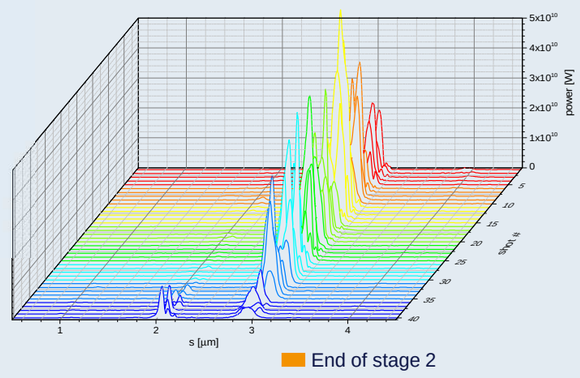
Stage 1



Stage 2



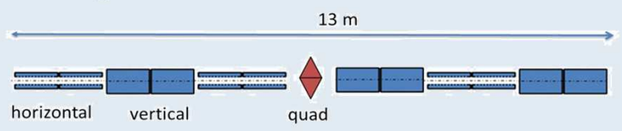
End of stage 1



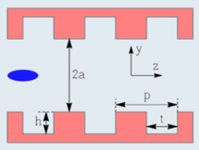
End of stage 2

Ingredients

Corrugated structure

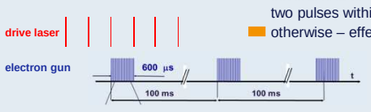


Depth, h	0.5	mm
Gap, t	0.25	mm
Period, p	0.5	mm
Half aperture, a	0.7	mm
Half width, w	0.6	mm



Drive laser

- several kHz to modulate at least two pulses within a train
- otherwise – effective rep.rate 10 Hz



Ti:sapphire based regenerative amplifiers.

wavelength	pulse duration	pulse energy	repetition rate	peak power	sync. possible
0.8μm	100fs	1-8mJ	1-10kHz	10-80GW	yes

Ytterbium based diode-pumped regenerative amplifiers

1.03μm	200fs	10mJ	1kHz	50GW	yes

>2μm amplifiers, e.g.
Cr:ZnSe

2.5μm	185fs	1uJ	1kHz	5GW	tbd

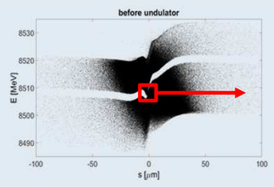
Ho:YLF

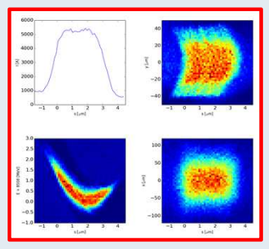
2.05μm	3ps	30mJ	1kHz	>3GW	tbd

Parametric amplifiers

Emittance spoiler

- 8.5 GeV electron beam
- Foil slot gap +/- 0.35mm
- Challenging to obtain sharp current edges



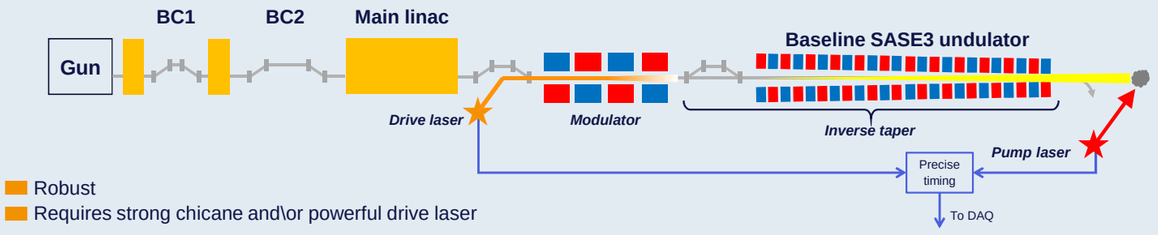


Modulator

- Electromagnetic and permanent magnet solutions
- 1.4T effective field
- 400mm period
- 1um resonant

[7]: XLEAP

Layout



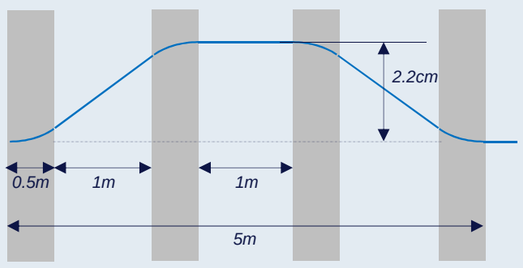
- Robust
- Requires strong chicane and\or powerful drive laser

- Numerical simulation results:
  SASE3-type undulator
  Simulated 8.5GeV ebeam with 3.5um lasing window
  modulated at 40 MeV p2v with 2um wavelength

Photon energy (eV)	600	870	1000	1500	2300
Undulator cells	6	7	6/7	8	8
Duration (as, fwhm)	500	500	400/550	300	300
Peak power (GW)	600	500	100/650	800	400
Pulse energy (μJ)	350	300	45/350	250	100

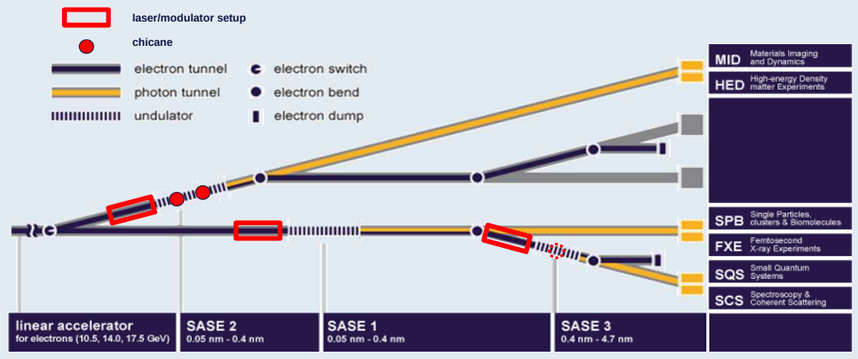
Chicane

- Considered for installation in the middle of SASE3 undulator
- $B = 0.85T$
- $E_e = 8.5GeV$
- $R_{56} \approx -450\mu m$



Location

- SASE1: lots of space, needs chicane (upgradable to HXRSS)
- SASE2: 2 chicanes present, serious space limitations
- SASE3: chicane is foreseen, high scientific interest



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