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Compact

D2.2 Status

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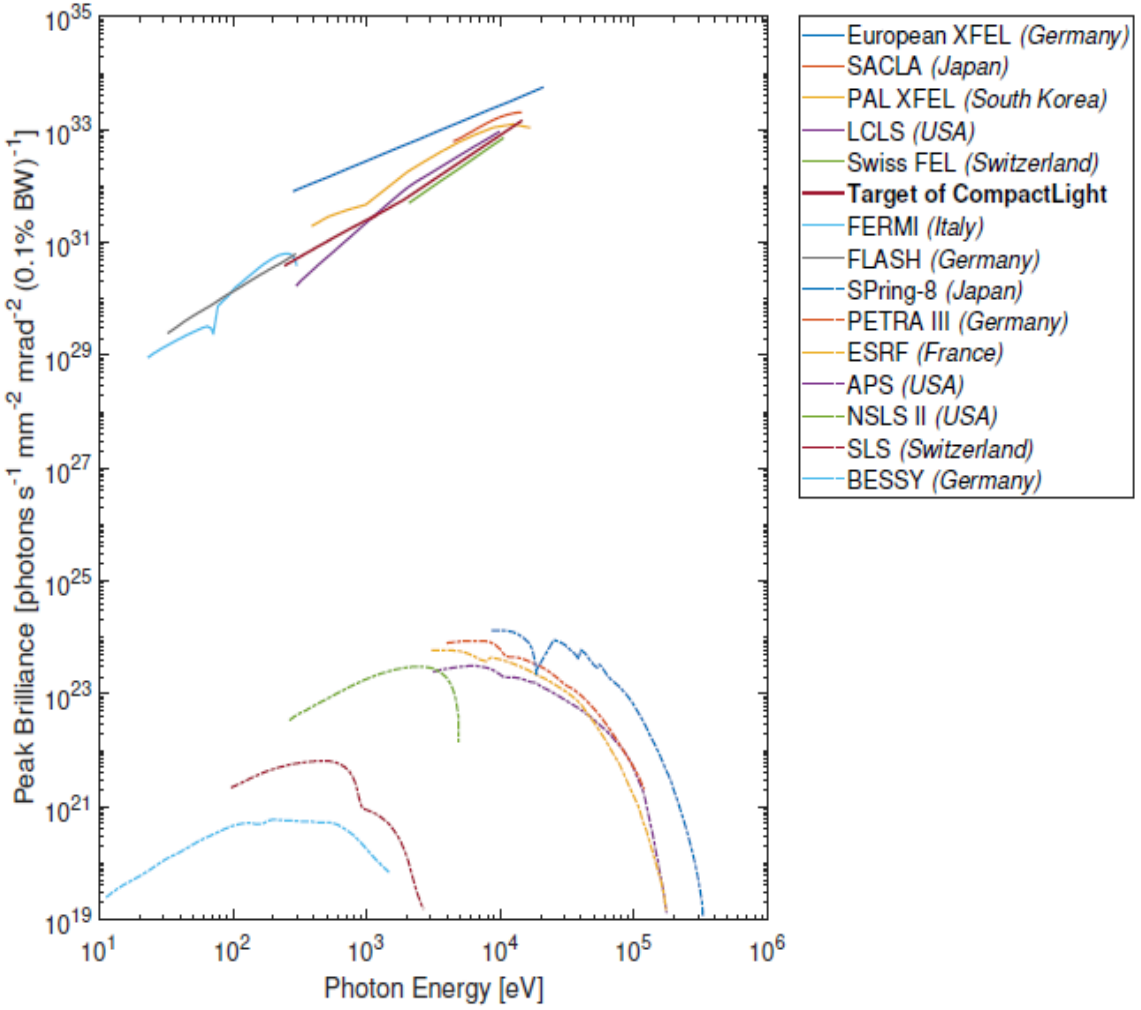
On behalf of the CompactLight Partnership

D2.2: "FEL design with accelerator and undulator requirements to achieve the specification", due by Dec. 31, 2019

1. Identifies the main parameters of CompactLight FEL
2. Collects recommendations from all the WPs as for the accelerator and the undulator specs.
3. Provides an overview of the facility concept by illustrating:
   - the main features of the project
   - the operating modes
   - sub-systems concepts and/or technical requirements.



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Guidelines to design

a) The CL design reflects a 10-years (2027) ahead user facility.
   - *this impacts the risk level below*

b) Surpasses state-of-the-art XFELs in peak and average brilliance, in a specific ν-E region
   - *This specifies the ultimate FEL performance*

c) Affords medium-risk technological R&D
   - *e.g., S-band vs. C-band vs. X-band Gun*

d) Affords low-risk physics
   - *e.g., optical FEL shaping vs. short e-bunches*

e) Results an advanced cost-effective XFEL user-facility
   - *This sets cost vs. performance decisions*

	SwissFEL		CompactLight	
	SX	HX	SX	HX
lambda [nm]	0.7 - 5.0	0.1 - 0.7	0.6 - 5.0	0.08 - 0.6
photon energy [keV]	0.25 - 1.77	1.77 - 12.4	0.25 - 2.0	2.0 - 16
undulator tech.	Apple-X	IVU: LP, VG		
rep. rate [Hz]	100	100	100-1000	100
pulse duration fwhm [fs]	< 20	> 1	0.1 - 50	1 - 50
pulse energy [uJ]	10 - 1000	10 - 1000	< 300	< 300
beam energy [GeV]	3.0	5.8	2.0	5.5
charge [pC]	10 - 200	10 - 200	75	75
normalized emittance slice rms [mm mrad]	0.25	0.25	0.20	0.20
normalized emittance proj. rms [mm mrad]	0.40	0.40	0.40	0.40
peak current [kA]	3	3	1	5

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Contents

1 Facility Concept 5
- 1.1 CompactLight FEL . . . 5
- 1.2 Layout . . . 6
- 1.3 Tables of Parameters . . . 8

2 Injector 9
- 2.1 Layout . . . 9
- 2.2 Radiofrequency . . . 9
- 2.3 Beam Dynamics . . . 9
- 2.4 Tables of Parameters . . . 10

3 Main Linac 11
- 3.1 Layout . . . 11
- 3.2 Bunch Length Compressors . . . 11
- 3.3 Accelerating Structures . . . 12
- 3.4 RF Distribution System . . . 12
- 3.5 Magnetic Lattice . . . 14
- 3.6 Beam Distribution System . . . 15
- 3.7 Tables of Parameters . . . 17

4 Undulator 19
- 4.1 Requirements . . . 19
- 4.2 Technology . . . 20
- 4.3 Lasing . . . 20
- 4.4 Tables of Parameters . . . 22

5 Photon Transport 23
- 5.1 Layout . . . 23

Established at the Helsinki meeting

C-band → X-band, + K-band linearizer
Velocity bunching

2-stage magnetic compression
Twin pulses, bam distribution system
for FEL pump-FEL probe

H-SCU + in-vacuum CPMU
afterburner

Waiting fo Vitaly G. (informed)

Layout

Baseline:

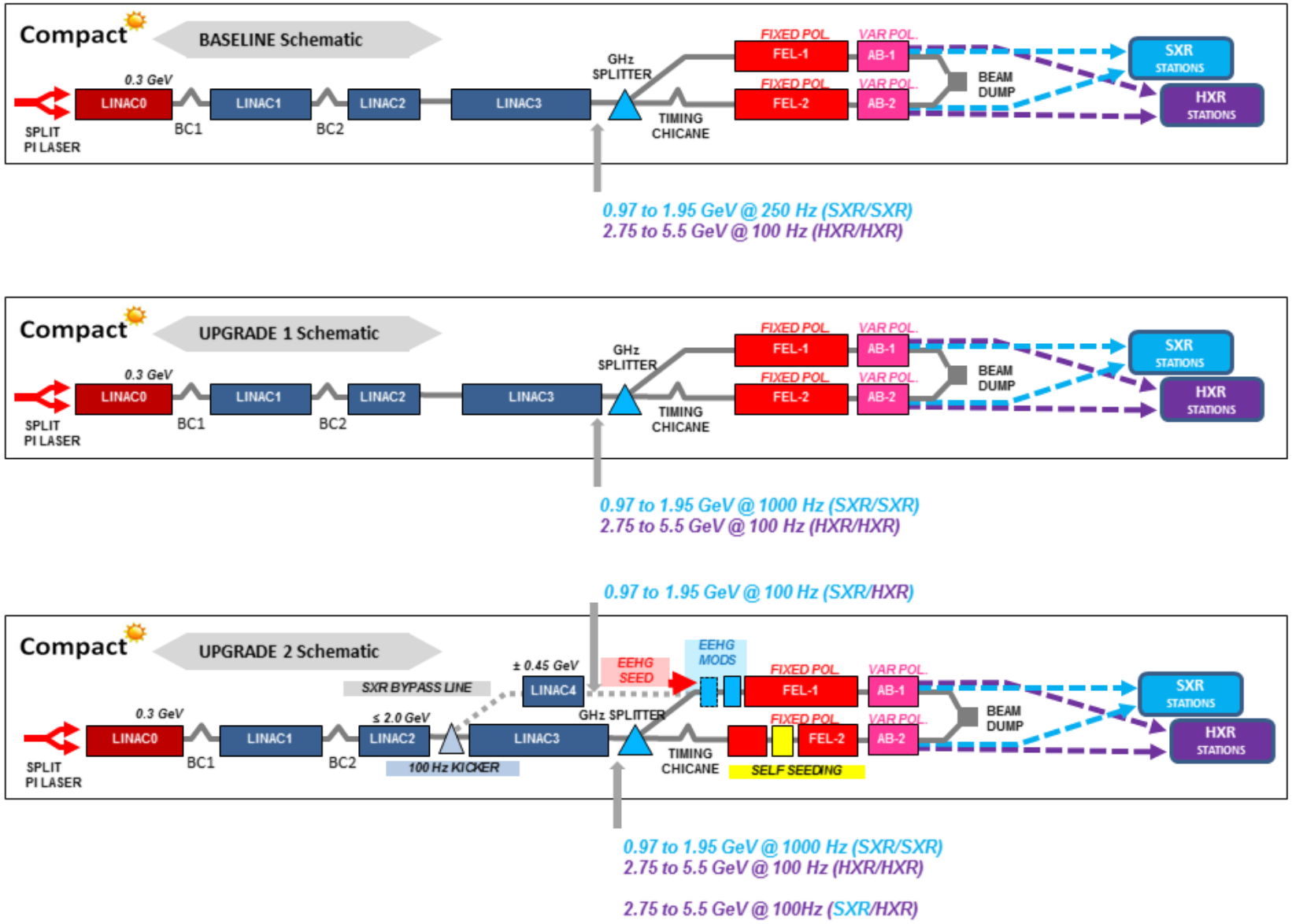
- Twin bunches (2-colors)
- RF in dual mode
  - SXR @250Hz
  - HXR @100Hz
- Variable pol.

Upgrade-1:

- + RF in dual source
  - SXR @1kHz

Upgrade-2:

- + 100 Hz kicker
  - SXR & HXR @100Hz
- Seeding (self-, external)



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FEL operating mode

Table 1: Target features of CompactLight FEL. Peak brillinace is in unit of ph/s/mm^2/mrad^2/0.1%bw(*).

Parameter	Unit	Soft X-ray	Hard X-ray
Max. repetition rate	kHz	1	0.1
Photon energy	keV	0.25 – 2.0	2.0 – 16.0
Wavelength	nm	5.0 – 0.6	0.6 – 0.08
FEL tuning range at fixed energy		×2	×2
Peak brilliance @16 keV	(*)		10^{33}
Pulse duration	fs	0.1 – 50	1 – 50
Polarization		variable, selectable	
Two-pulse delay	fs	±100	±100
Two-colour separation	%	20	10
Synchronization	fs	< 10	< 10

Table 2: Operating modes of CompactLight FEL. B = baseline; U1 = Upgrade-1; U2 = Upgrade-2; HH = twin hard x-ray pulses; SS = twin soft x-ray pulses.

Operating Mode	FEL-1 λ-range	FEL-2 λ-range	L0-L1-L2-L3 Rep.Rate [Hz]	L3 Final E [GeV]	L4 Rep.Rate [Hz]	L4 Final E [GeV]
BASELINE						
B-HH	HXR	HXR	100	2.75-5.5		
B-SS	SXR	SXR	250	0.95-1.95		
B-HH	HXR	HXR	100	2.75-5.5		
UPGRADE-1						
U1-HH	HXR	HXR	100	2.75-5.5		
U1-SS	SXR	SXR	1000	0.95-1.95		
UPGRADE-2: U1 plus extra mode						
U2-SH	SXR	HXR	100	2.75-5.5	100	0.95-1.95

Table 5: Electron beam parameters at undulator entrance.

Parameter	Value
Max. Energy	5.5 GeV @ 100 Hz
Max. Peak Current	5 kA
Norm. Slice Emittance	0.15 μm rad
Bunch charge	< 100 pC
Bunch duration (RMS)	< 50 fs
Slice Rel. Energy Spread	10^{-4}
Max. repetition rate	1 kHz

Table 11: Photon energy ranges and corresponding discrete electron beam energies at the undulator to cover the whole CompactLight spectral range. A minimum peak brilliance of $10^{33} ph/s/mm^2/mrad^2/0.1\%bw$ is considered. Linear polarization only is assumed.

Parameter	Unit	SXR			HXR		
Repetition rate	kHz	0.1, 0.25, 1			0.1		
Photon energy range	keV	0.25-0.5	0.5-1	1-2	2-4	4-8	8-16
Electron beam energy	GeV	0.97	1.37	1.95	2.75	3.9	5.5
Minimum peak current	kA	0.35	0.65	0.93	1.5	2.5	5
Slice energy spread (RMS)	%	0.05	0.04	0.03	0.02	0.015	0.01
Normalised slice emittance (RMS)	μm rad	0.2					
Bunch charge	pC	75					

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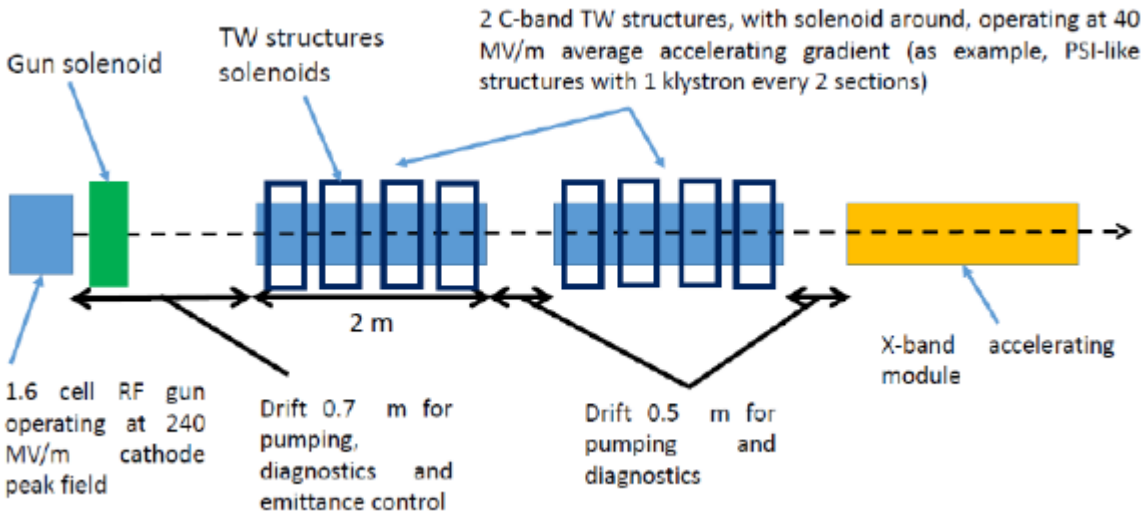

Table 3: Injector beam parameters.

Parameter	At gun exit	At L0 exit	Units
Repetition rate	0.1, 0.25, 1		kHz
Charge	75		pC
Proj. norm. emittance (RMS)	0.15 (x), 0.15 (y)		μm rad
Energy	6	280	MeV
Rel. enegry spread (RMS)	0.7	0.5	%
Bunch duration (RMS)	1.2	0.4	ps
Peak current (core)	20	60	A

- **Baseline:** C-band inj. + K-band linearizer
- **Upgrade:** X-band inj. + K-band linearizer

❑ Both guarantee 0.1 – 1 kHz rep. rate

❑ Transverse emittance at 1 kHz can be relaxed

❑ X-band inj. is more compact and utilizes same RF technology of the main linac

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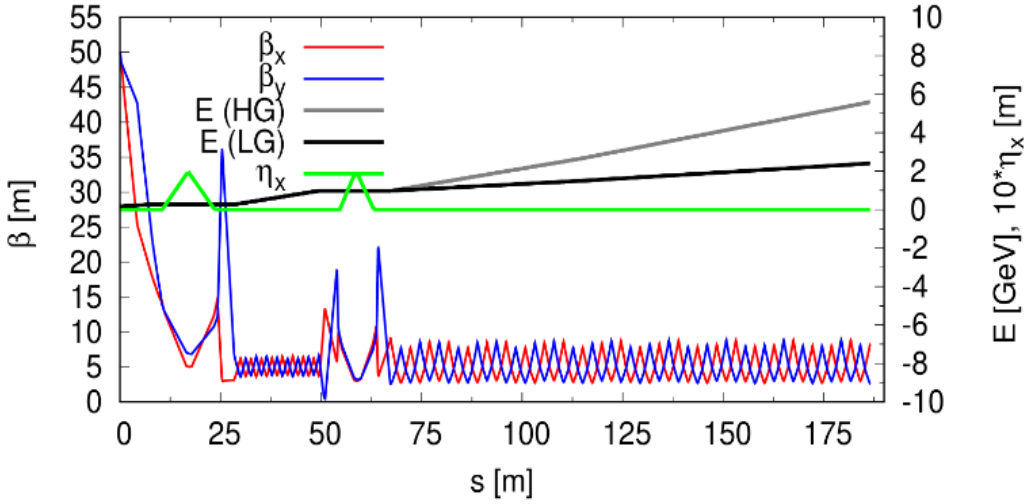
- **Baseline:** "dual mode" for 0.1 & 0.25 kHz rep. rate
- **Upgrades:** "dual source" for up to 1 kHz rep. rate

❑ > 70% RF-to-magnets filling fraction
❑ <50 μm-quads, <100 μm-RF misalignment errors
❑ 7 m average betatron functions

Parameter	Unit	Dual mode		Dual source	
Operating Mode		B		U1, U2	
Repetition rate	kHz	0.1	0.25	0.1	1
Linac active length	m	83			
Number of structures		92			
Number of modules		23			
Number of klystrons		23		23 + 23	
Peak acc. gradient	MV/m	65	32	65	30.4
Energy gain per module	MeV	234	115	234	109
Max. energy gain	MeV	5382	2649	5382	2507



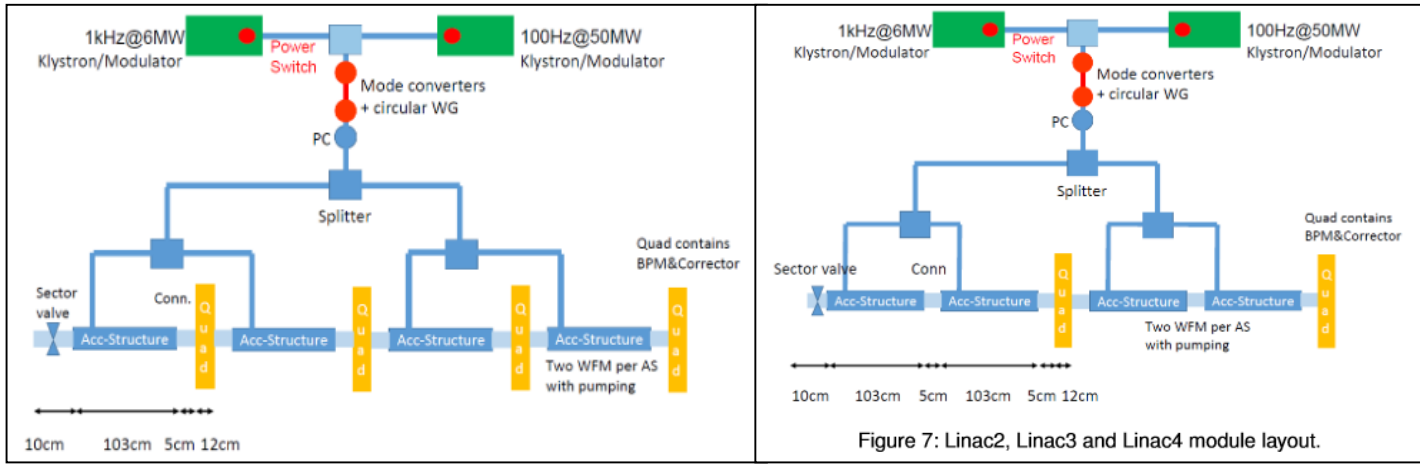
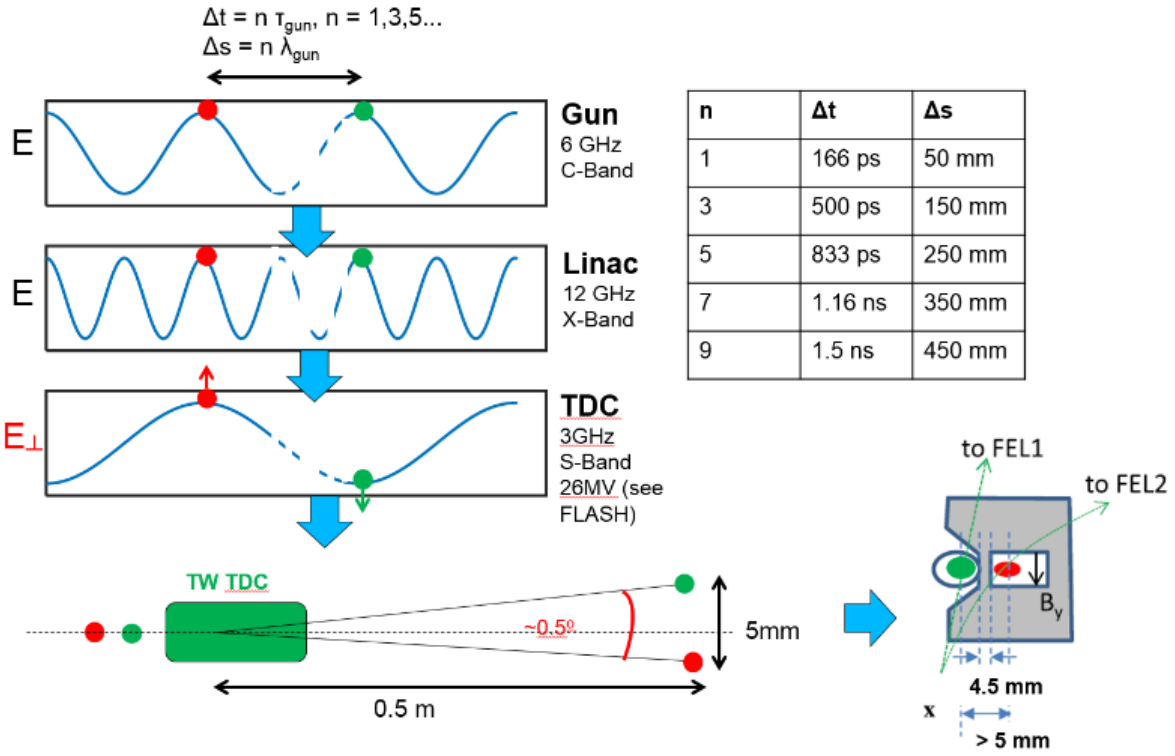


Figure 7: Linac2, Linac3 and Linac4 module layout.

e-Beam distribution system



n	Δt	Δs
1	166 ps	50 mm
3	500 ps	150 mm
5	833 ps	250 mm
7	1.16 ns	350 mm
9	1.5 ns	450 mm

1. **Twin bunches** at the injector, separated by **0.5 ns** (e.g., 3 C-band cycles)
2. 30 MV S-band **TDC + septum** for splitting at high energy
3. High energy **dog-leg, 20 m x 2.5 m** footprint
4. High energy **chicane (10 m)** and at **split-and-delay** photon beamline for synchronization and fine tuning.

- Alternative schemes include:
  - Twin bunches, 55 MeV S-band linac + septum
  - Single bunch, beam scraping at low energy + septum

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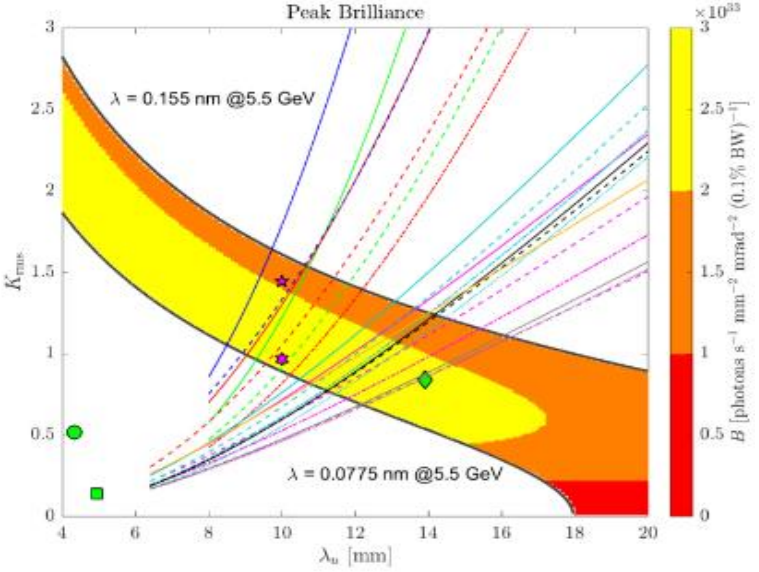

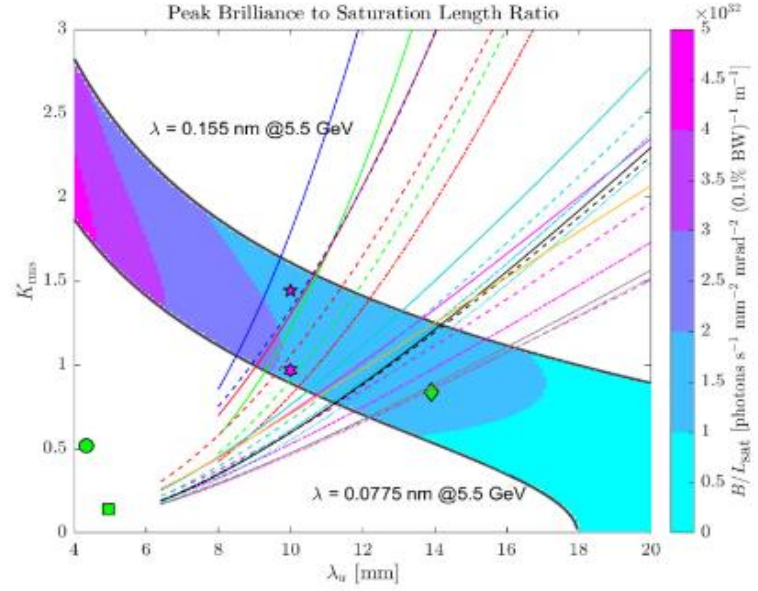

Table 10: Results of GENESIS time-dependent simulations.

Parameter	CPMU	Delta	Hybrid	SCU
Saturation power [GW] (pulse average)	9.1	8.9	7.6	9.8
Saturation length [m]	24.5	26.5	29.1	15.6
Sat. pulse energy [μJ]	49	48	29	54
FWHM bandwidth [10^{-3}]	0.987	0.975	0.996	1.16
Peak brightness [10^{33} × × ph/s/mm^2/mrad^2/0.1%bw]	2.39	2.37	1.98	2.18

- **Baseline, Upgrade-1:** SASE
- **Upgrade-2:** EEHG SXR, self-seeding HXR

- ❑ FEL-1 and FEL-2 are identical
- ❑ × 2 λ-tuning range at each of the 6 fixed e-beam energies
- ❑ Helical SCU + in-vacuum CPMU afterburner

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Next steps

1. Finalize the undulator description and tables – *Thomas, Neil*
2. Include concept and requirements of photon transport – *Vitaly*
3. Submission to WP1 by Dec. 8
4. Submission to EU by Dec. 15