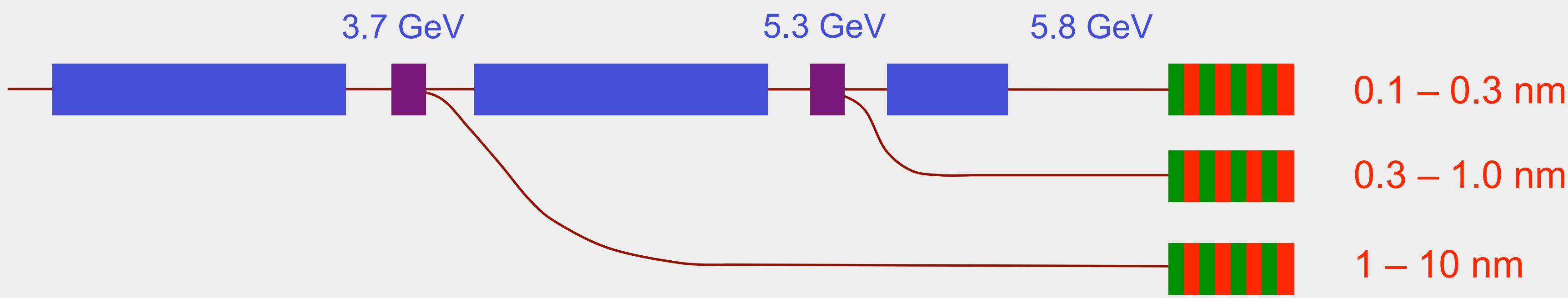
Design Consideration for the PSI-XFEL

Sven Reiche
FELSI - Meeting
16.9.2008

Current Design



	FEL 1	FEL 2	FEL 3
Wavelength	0.1 - 0.3 nm	0.3 - 1.0 nm	1 – 10 nm
Beam Energy	3.3 - 5.8 GeV	3.2 - 5.3 GeV	3.7 GeV
Period Length	15 mm	36.6 mm	52 mm
K-Value	1.2	1.2 – 2.7	1.4 – 6.2
Und. Type	In-vac	Apple II	Apple II
Tuning	Energy	Energy+Gap	Gap

Problems with Current Design

FEL 1: Ok – defines overall linac design (energy, beam brightness)

FEL 2:

1. Coupled with FEL 1 by energy. Limits actual wavelength range.
2. Covers wavelength range with duel set of X-ray/VUV optics.
3. Undulator longer than FEL 1 beamline.

FEL 3:

1. Huge tuning range (x10) by K-value alone. Long period length required.
2. With given period length of 52 mm the max K-value of 6.2 requires a gap of 2 mm or below, strong wakefield issues
3. Inefficient high beam energy yields excessivly large K-values for longest wavelength.

Input/Requests from User Side

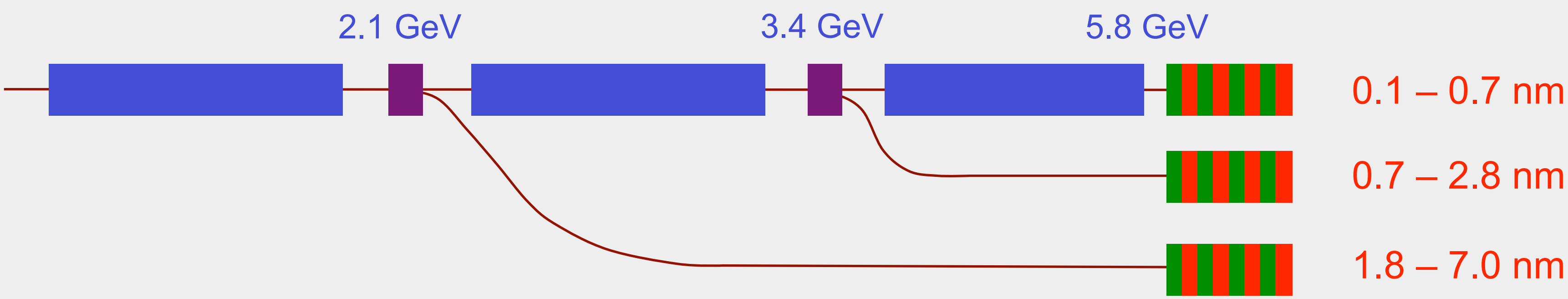
- Different optics below and above 2 keV (0.6 nm). Avoid possible double instrumentations of FEL beamlines (e.g. old FEL 2 beamline)
- Strong demand for 14.4 keV (0.085 nm) – make it baseline?
- Lowest energy with strong interest at C-edge 285 eV (4.2 nm)
- Si-edge 99 eV (12 nm) desirable

- Tunability and polarization control.
- Option for short FEL pulse (< 50 fs).
- Seeding option (at least in the VUV).
- Spontaneous radiator.
- THz source with arrival time up to 1 ns prior to X-ray pulse.

Input/Request from Insertion Device Group

- FEL 1 in vacuum undulator with variable gap, though main method of tuning is by energy. Planar polarization.
- FEL 2 and 3: APPLE type undulator with minimum gap of 6.5 mm.
- Rectangular vacuum chamber feasible. Minimum wall thickness of 500 microns -> 5 mm inner diameter of vacuum chamber.
- Same length of undulator modules for single design of supporting structure
- Module length of 4 m preferred over 4.5 m
- Open for discussion: only last 3 Modules in FEL 2 and 3 are of APPLE-type, planar the rest:
  - Saturation at undulator exit (fixed source point for optics)
  - Does not allow superradiant regime or post-saturation taper
  - Does not work for cascading (HGHG)

Putting it together: Proposed New Design - Basic Layout



	FEL 1	FEL 2	FEL 3
Wavelength	0.1 – 0.7 nm	0.7 – 2.8 nm	1.8 – 7.0 nm
Beam Energy	2.2 - 5.8 GeV	3.4 GeV	2.1 GeV
Period Length	15 mm	40 mm	40 mm
K-Value	1.2	1.0 – 3.2	1.0 – 3.2
Und. Type	In-vac	APPLE	APPLE
Tuning	Energy	Gap	Gap

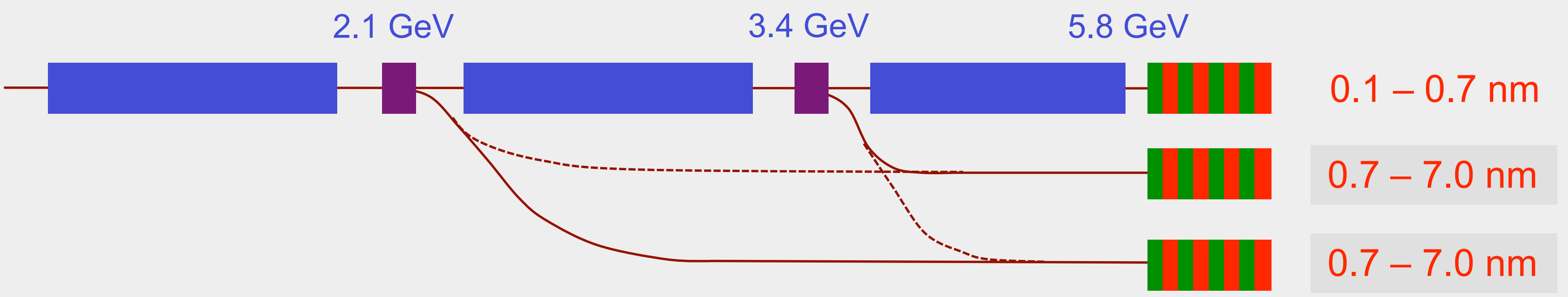
Improvements/Changes

- Linac is fixed till second extraction point at 3.4 GeV. Rest of Linac is used for energy tuning of hard X-ray FEL (FEL 1).
- FEL Operation is decoupled from other FEL beamlines.
- Wavelength range is roughly defined by available optics, resulting in one hard X-ray and two VUV beam lines
- Module length is 4m to allow for lower beta-function of 10 m in the VUV beamlines.
- FEL 2 and FEL 3 are using the same undulator type. Modules can be exchange among the beam lines and only one type of spare module is needed for the VUV FELs.
- Requirement of minimum gap of 6.5 mm is achieved for VUV beamlines.
- VUV beamlines have a tuning range of a factor 4. Extraction energy can be optimized to change wavelength range (e.g. 3.7/2.4 GeV for a VUV range from 0.6-6 nm)

FEL Performance (Genesis SASE Simulations)

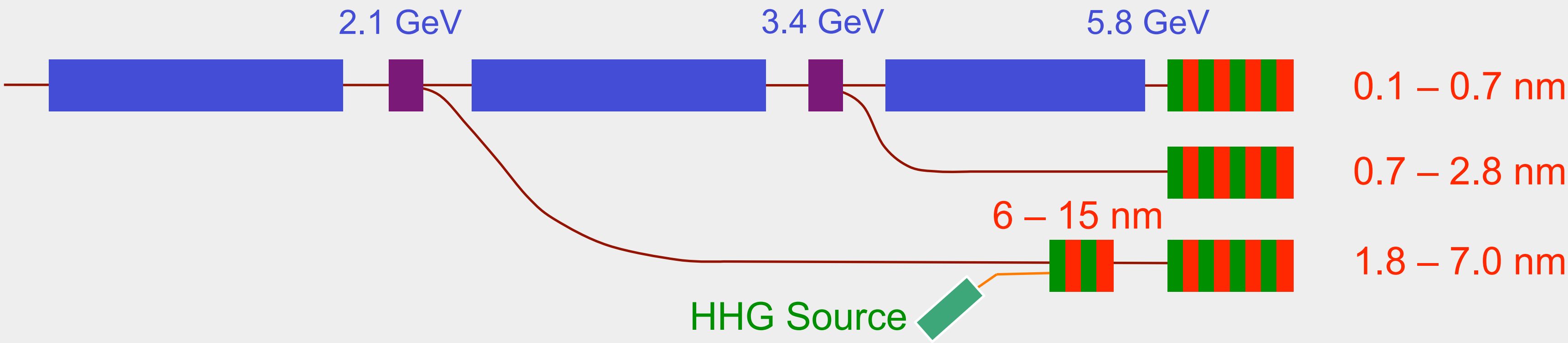
	Units	FEL 1		FEL 2		FEL 3		FEL 3 - Modulator	
Wavelength	nm	0.1	0.7	0.7	2.8	1.8	7	6	15
Photon Energy	keV	12.00	1.71	1.71	0.43	0.67	0.17	0.20	0.08
Beam Energy	GeV	5.8	2.2	3.4	3.4	2.1	2.1	2.1	2.1
Period Length	mm	15	15	40	40	40	40	50	50
K (planar)	-	1.20	1.21	1.05	3.22	1.02	3.13	2.47	4.27
Beta-function	m	15	15	10	10	10	10	10	10
Saturation Length	m	**39.27**	21.52	**41.52**	25.54	**32.81**	20.08	25.14	23.11
Gain Length	m	2.49	1.24	2.24	1.23	1.60	0.96	1.18	0.94
Peak Power	GW	2.04	1.60	5.16	7.76	5.06	6.38	6.88	10.41
Pulse Energy	mJ	0.13	0.09	0.32	0.51	0.33	0.46	0.48	0.81
Peak Brilliance	#/s mm^2 $mrad^2$ 0.1%	**1.2E+32**	7.4E+30	**2.3E+31**	1.8E+30	**5.5E+30**	2.7E+29	2.7E+29	6.3E+28
Bandwidth, rms	%	0.04	0.08	0.12	0.31	0.17	0.42	0.45	0.60
Beam Size, rms	µm	19.33	34.28	41.52	58.07	49.51	95.56	101.07	179.21
Divergence, rms	µrad	1.46	5.87	4.88	15.84	9.29	30.24	26.12	52.15
Intensity (50 m drift)	J/cm^2	0.72	0.03	0.17	0.03	0.05	0.01	0.01	0.00

Possible Extension 1



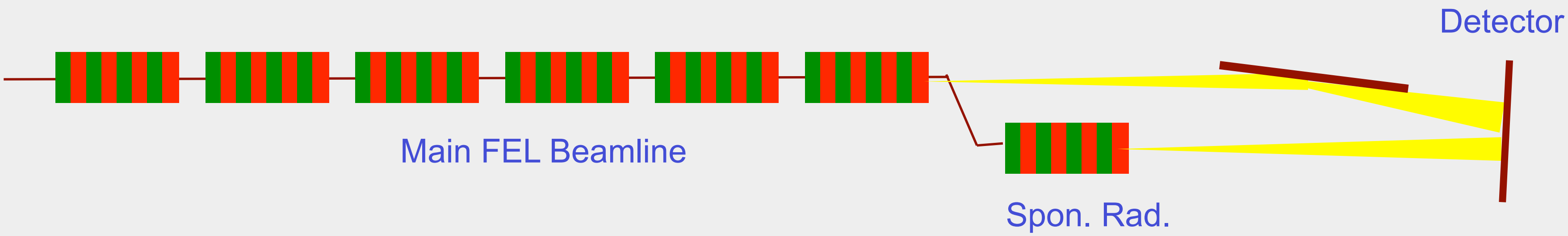
- Because both VUV FEL are using the same undulator type, the wavelength range can be extended by adding a switch yard of the bypass lines.
- Allows for better distribution of experiments on the VUV beamlines (e.g. supplying C-edge to 2 users at the same time).
- Discussion: Can beam be transported through main linac with RF off between the two extraction points? If so, bypass lines can be avoided. Otherwise the space can be used for an e-beam dignostic section.

Possible Extension 2

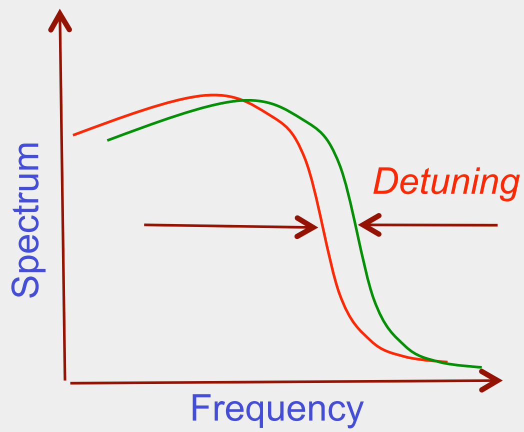


- Seeding done with HHG source.
- Below 6 nm puts huge demands on HHG source (>10 nJ of seed pulse). Better with initial stage at longer wavelength and one HGHG step.
- Modulator Undulator: 50 mm period, K: 2.4 – 4.3, 4-5 Modules.
- Can be used to run SASE FEL at 12 nm for Si-edge.

Possible Extension 3 – Spontaneous Radiation

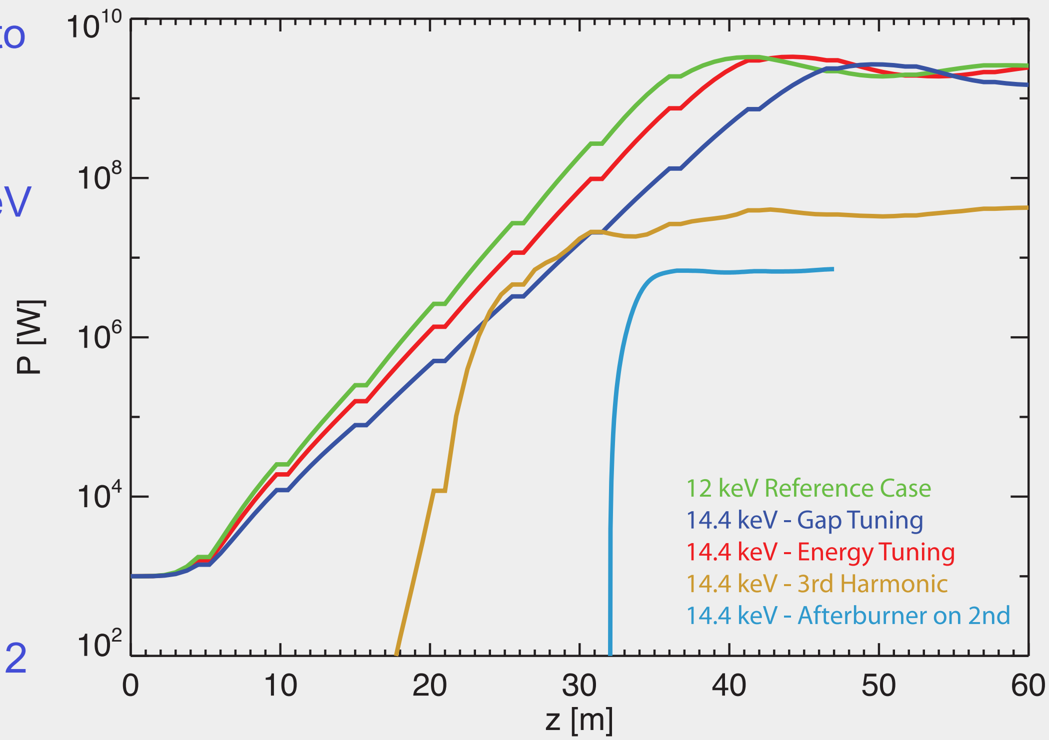


- A reference module would be highly useful for beam based K-measurement (Tolerance $\Delta K/K \sim 10^{-4}$).
- Redirect spontaneous radiation of FEL beamline module and reference module into same diagnostic but spatially separated.
- Relative measurement eliminates jitter in electron energy and charge.
- During FEL operation, radiator can be freely used by other users.



Possible Extension 4 – 14.4 keV Photons

- Several methods are avaiable to reach 14.4 keV photon energy:
  - Open gap at 5.8 GeV
  - Increase energy to 6.4 GeV
  - 3rd harmonic radiation of operation at 4.8 keV
  - "Afterburner" tuned to 2nd harmonic after 7.2 keV operation reached saturation.
- Higher energy most desirable solution, increasing saturation length by 10% with respect to 12 keV operation.
- Opening the gap is simplest solution but increases saturation length by 25%.



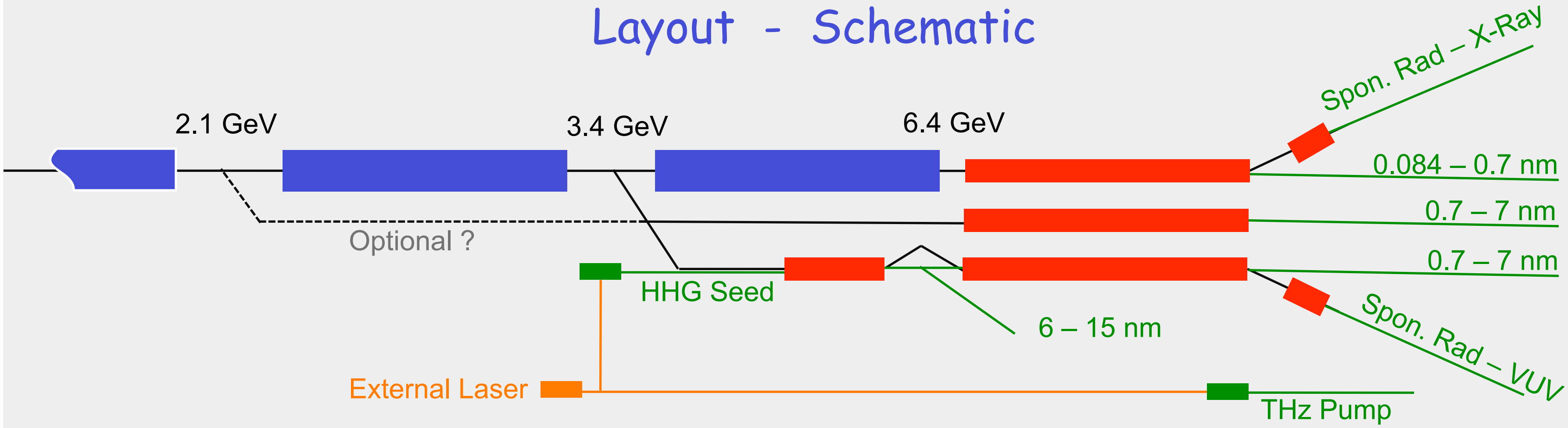
Possible Extension 5 – Short Pulses

- Stringent space requirements does not allow any beam manipulation between the exit of the linac and the beginning of the X-ray FEL.
- Remaining option:
    - Emittance spoiler in bunch compressor. Resulting pulse length is about 1 fs.
    - Slicing of chirped SASE FEL pulse. Resulting pulse length is 10 fs and longer.
    - Ultra-low charge operation, resulting in short electron bunches (to be studied).
- In the VUV with seeding option, the FEL can be driven in the superradiant regime. Pulse length down to 1 fs.

Possible Extension 6 - THz Source

- As a independent source easy to generate with a bending magnet and a compress electorn bunch but:
    - THz pulse is a pump and has to arrive before the X-ray/VUV pulse.
    - Delay of up to 1 ns between THz and X-ray pulse are requested.
- Deriving both pulses from a single electron bunch is difficult (Only option is in last bunch compressor but a large THz signal means strong CSR effects, which is counter-productive).
- Solution 1: Tandem acceleration of 2 bunches in different RF buckets.
- Solution 2: External, low energy injector, synchronized to main linac.

Layout - Schematic



Undulator Space Requirements:

- Main FEL Lines: ~ 60 m (50% overhead at 1 Ångstrom)
- Modulator/Soft UV FEL: ~ 20 m
- Dispersion Section for Seeding: ~ 10 m
- Spontaneous Radiation Undulator: ~ 5 m (1 Module)
- Separation between Main FEL and Spon. Rad. Und.: > 5 m

To be Discusses/Investigated

- Baseline Parameters for electron beam. Current undulator length is based on design paramters with 50% overhead (which allows to reach saturation at 1 Å with the CTF gun – s2e simulations)

- Seeding strategies:
    - Can we seed at 7 nm and below?
    - Is HGHG cascading beneficial?
    - Self-seeding approach?
    - Superradiant regime?

- Thz source: Same bunch technique vs tandem operation vs external source.

- Bypass line + switch yard. Can electron beam diagnostic line be integrated?

To be Discusses/Investigated (cont')

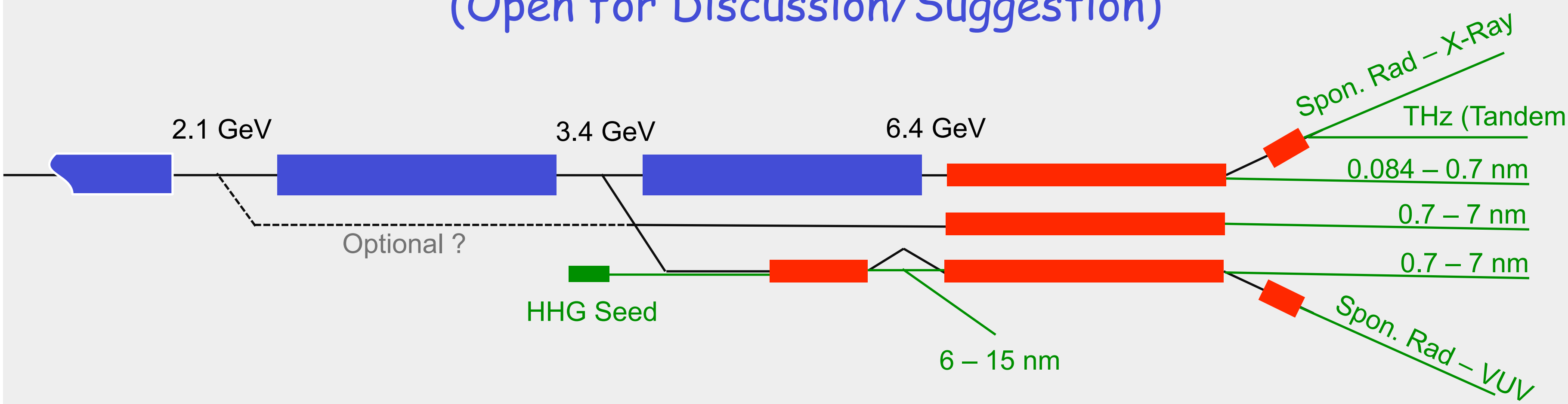
- 14.4 keV photon energy as baseline parameter or optional future upgrade? Can electron beam energy increased to 6.4 GeV?

- Layout of undulator hall:
  - Fan vs Comb (including spontaneous radiator)
  - Vertical separation of X-ray/VUV beamlines
  - Move VUV FELs forward?
  - Space for dogleg/bend of spontaneous radiation undulator and THz source?

- Can electron beam energy chirp be controlled for X-ray slicing

Old/Optional Slides

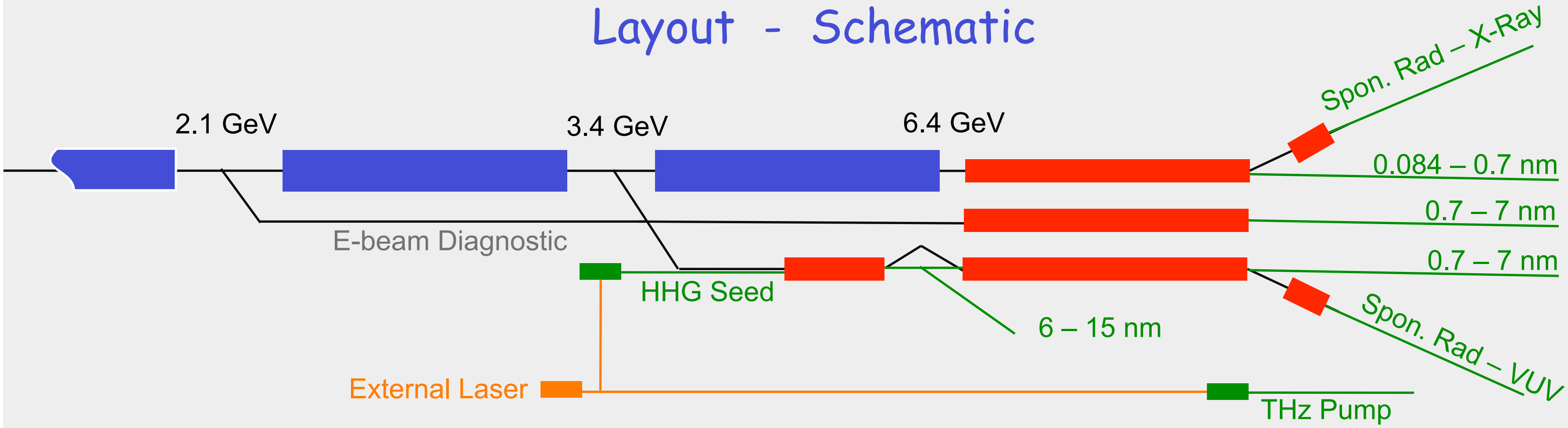
Final Layout - Schematic
(Open for Discussion/Suggestion)



Undulator Space Requirements:

- Main FEL Lines: ~ 60 m (50% overhead at 1 Ångstrom)
- Modulator/Soft UV FEL: ~ 20 m
- Dispersion Section for Seeding: ~ 10 m
- Spontaneous Radiation Undulator: ~ 5 m (1 Module)
- Separation between Main FEL and Spon. Rad. Und.: > 5 m

Layout - Schematic



- One 60 m X-ray FEL beam line, planar, tuned by energy.
- Two 60 m VUV FEL beam lines, APPLE-type, tuned by undulator gap with 2 selectable electron beam energies.
- 2 Undulator Modules for Spontaneous Radiation (X-ray and VUV).
- Long wavelength undulators for seeding purpose or SASE FEL.
- HHG source for seeding.
- THz Pump source (Plasma injector + dipole radiator).
- Extending beam energy range to reach 14.4 keV photon energy.
- Short pulse with chirped pulse and slicing, low charge operation and/or emittance spoiler slit in bunch compressor.