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WP2 Update

CompactLight Mid-Term Review, Helsinki July 2019

Jim Clarke, STFC Daresbury Laboratory, on behalf of the WP2 team

Objectives

With CompactLight we intend to:

- design a hard X-ray FEL facility ***beyond today's state of the art***,
- using the latest concepts for ***bright electron photo injectors***,
- using very high-gradient ***X-band structures*** at 12 GHz,
- using innovative compact ***short-period undulators***.

Compared to existing facilities, the proposed facility will benefit from

- a ***lower electron beam energy***, due to the enhanced undulator performance,
- be significantly ***more compact***, as a consequence both of the lower energy and of the high-gradient X-band structures,
- have a much ***lower electrical power demand***

CompactLight gathers the world-leading experts in these domains, united to achieve two objectives:

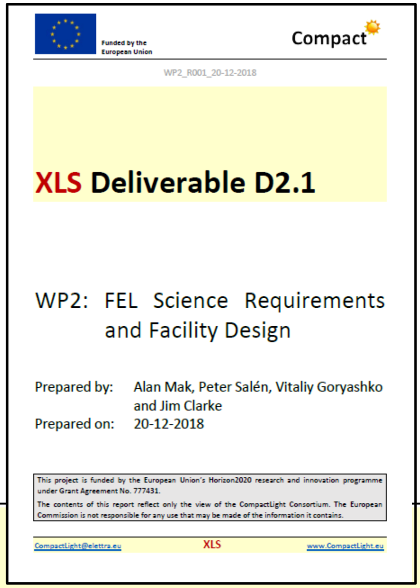
- ***disseminate X-band technology*** as a new standard for accelerator-based facilities and
- ***advance undulators*** to the next generation of compact photon sources,

with the aim of facilitating the widespread development of X-ray FEL facilities across and beyond Europe by making them more affordable to build and to operate.

Facility Parameters

Table 1: Main parameters of the CompactLight FEL.

Parameter	Unit	Soft-x-ray FEL	Hard-x-ray FEL
Photon energy	keV	0.25 – 2.0	2.0 – 16.0
Wavelength	nm	5.0 – 0.6	0.6 – 0.08
Repetition rate	Hz	1000	100
Pulse duration	fs	0.1 – 50	1 – 50
Polarization		Variable, selectable	Variable, selectable
Two-pulse delay	fs	$\pm$100	$\pm$100
Two-colour separation	%	20	10
Synchronization	fs	<10	<10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WP2_R001_20-12-2018

XLS Deliverable D2.1

WP2: FEL Science Requirements and Facility Design

Prepared by: Alan Mak, Peter Salén, Vitaliy Goryashko and Jim Clarke

Prepared on: 20-12-2018

Available at http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-374175

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ESSENTIAL USER REQUIREMENTS

- Photon energy range at the fundamental: 0.25 – 16.0 keV
- Variable, selectable polarisation
- Repetition rate 100Hz
- 2-colour operation with timing separation +/- 100fs and colour separation 20% in SXR and 10% in HXR
- Wavelength tuning primarily by undulator scanning with several discrete beam energies.
- Pulse duration 1 – 50 fs
- Even pulse spacing and <10fs synchronisation between FEL pulse and external laser.
- Competitive pulse energy

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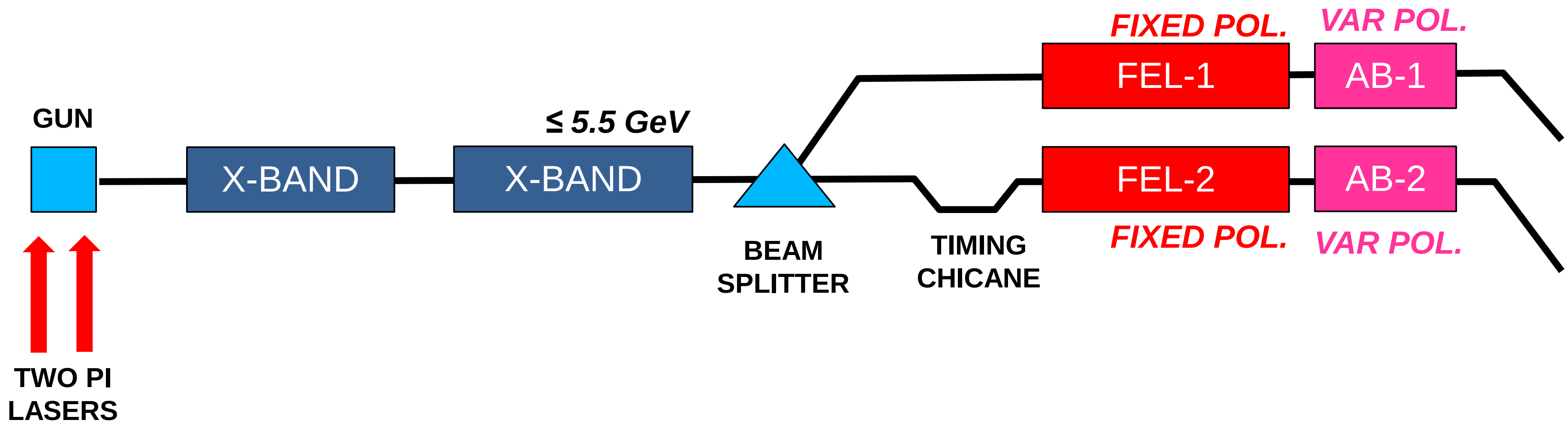
Underlying Principals

- We need a strong field undulator with short period and small gap to **minimise beam energy**, with period set appropriately to give a **factor of two wavelength tuning at each beam energy**, and **6 discrete beam energy working points to cover the whole range 0.25 – 16 keV**.
- The most **aggressive undulator technologies are not variably polarising**. Therefore the **variable polarisation should be provided by using an AFTERBURNER for the last one or two gain lengths**. In combination with a positive taper to suppress the fundamental while maintaining bunching growth we can then provide highly polarised FEL output.
- For pulses **separated independently in time and wavelength** we need in effect **a double electron bunch**. Schemes such as transverse wake/betatron oscillation to get lasing at separate sections of the electron bunch in different undulators have been demonstrated, but pulse energies are low (not all bunch used) and as each colour starts independently from noise **the undulator length is doubled**, the source **positions are widely separated longitudinally** and it is **difficult to also incorporate self seeding**.
- The selected option **is a double FEL**:
  - A **double bunch** (two PI laser pulses) with each bunch **having independent charge**, separated into two FEL lines (see next talk) with the **delay between the electron bunches controlled** with a magnetic delay line.
  - Total **undulator length is the same** but **building length is less**, the **delay, wavelength separation, polarisation, pulse length, bandwidth and pulse energy of the two pulses would be independently tunable, and their source positions** matched to the beamline needs. Also **pulse energies** would be high through using full bunch.
  - **To date, double pulses from FELs have been compromised** by using existing facilities which weren't designed for that purpose. **A specially designed and optimised double FEL will be truly world-leading and unique.**

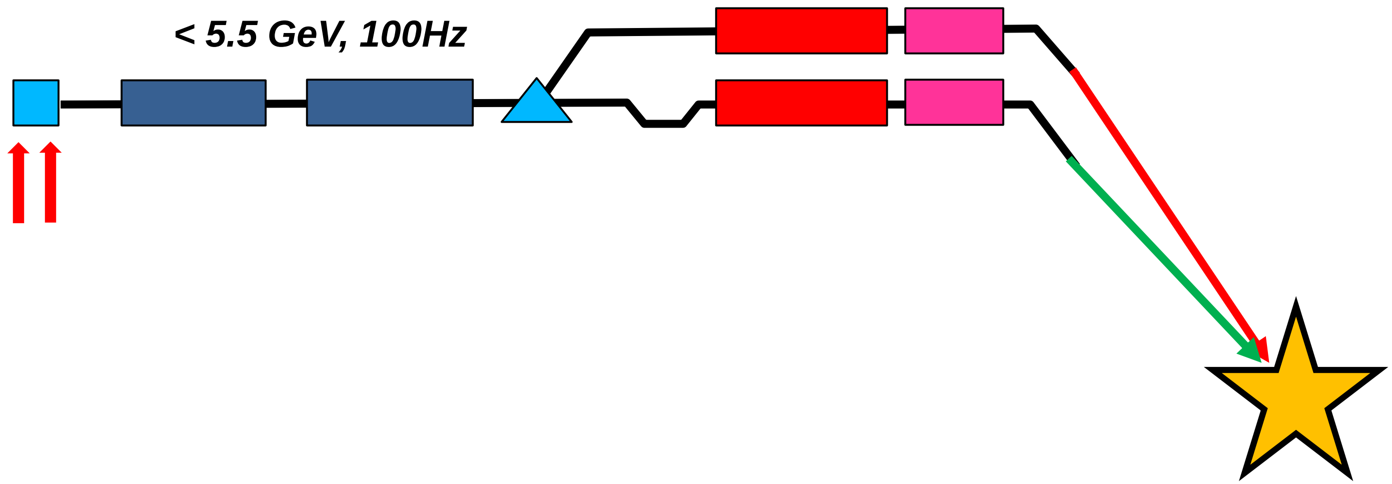
CORE MACHINE SCHEMATIC LAYOUT



Notes

1. Maximum Energy 5.5 GeV
2. Polarisation set by afterburners
3. Two bunches per macropulse
4. **Meets all of the Essential Requirements**

Operating Mode 1



FEL-1/FEL-2 producing independent pulses for one experiment at up to 16keV @ 100Hz

(two colour operation HXR, independent wavelengths)

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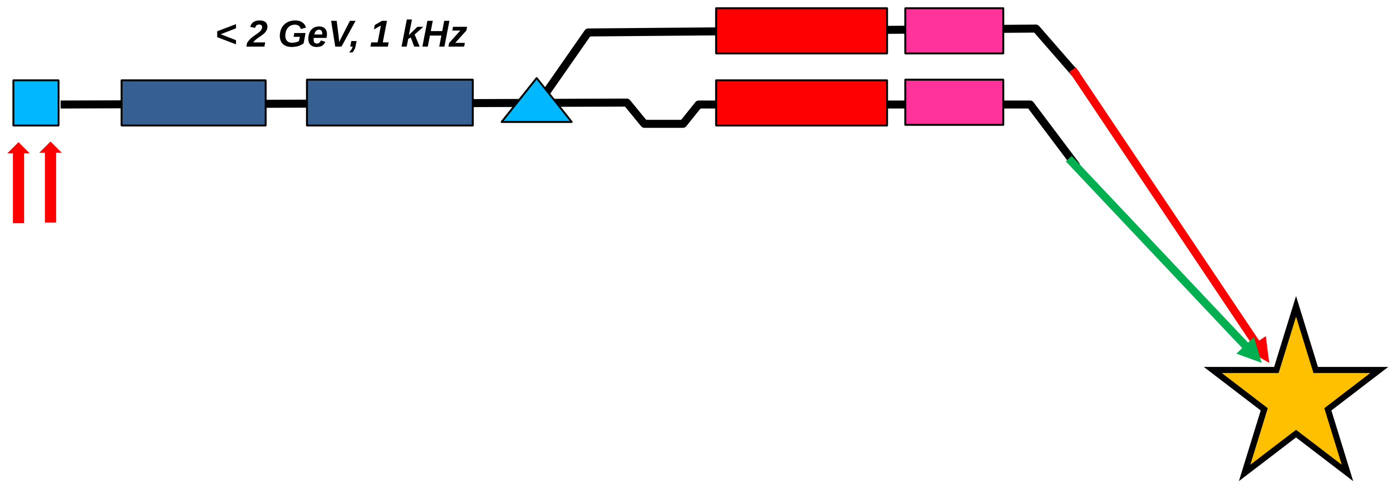
Operating Mode 2

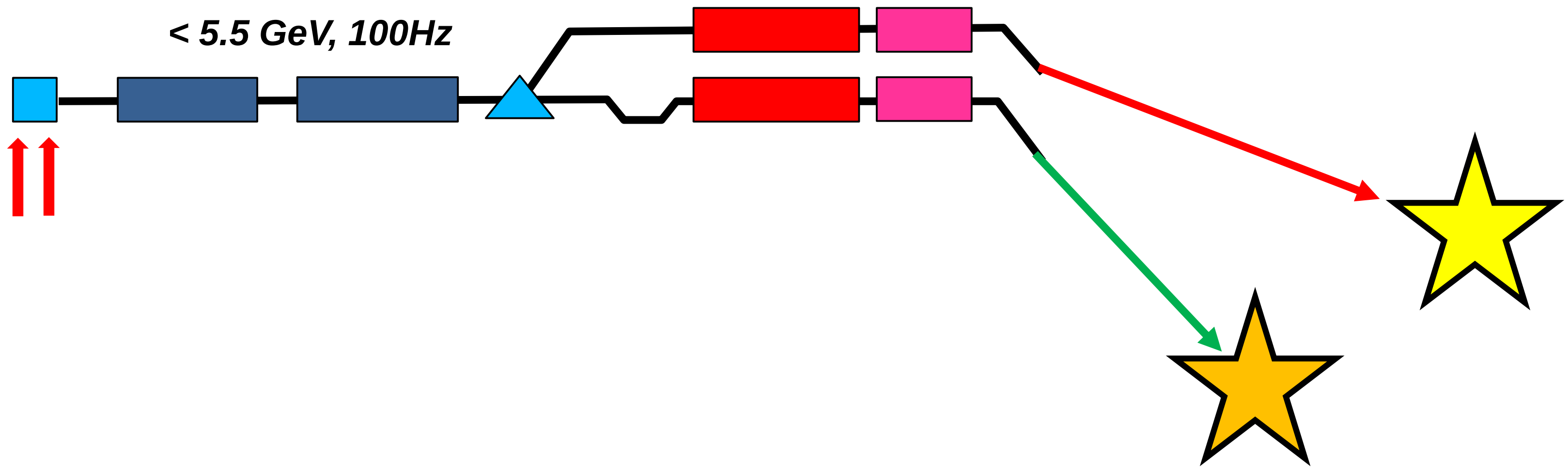


FEL-1/FEL-2 producing independent pulses for one experiment at up to 2keV @ 1 kHz

(two colour operation SXR, independent wavelengths)

Note:
SXR and HXR beamlines will be different – can’t simply use common beamline over full wavelength range

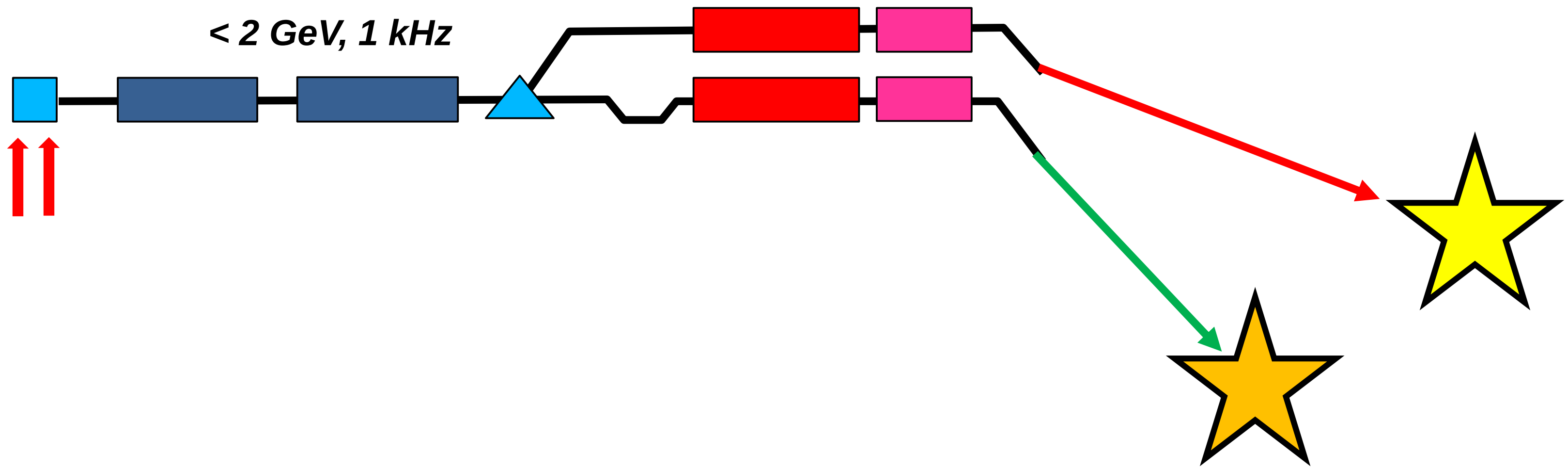
Operating Mode 3



FEL-1/FEL-2 producing independent pulses for two experiments at up to 16keV @ 100 Hz

(two simultaneous experiments running at 100Hz in HXR with independent wavelengths)

Operating Mode 4



FEL-1/FEL-2 producing independent pulses for two experiments at up to 2keV @ 1 kHz

(two simultaneous experiments running at 1 kHz in SXR with independent wavelengths)

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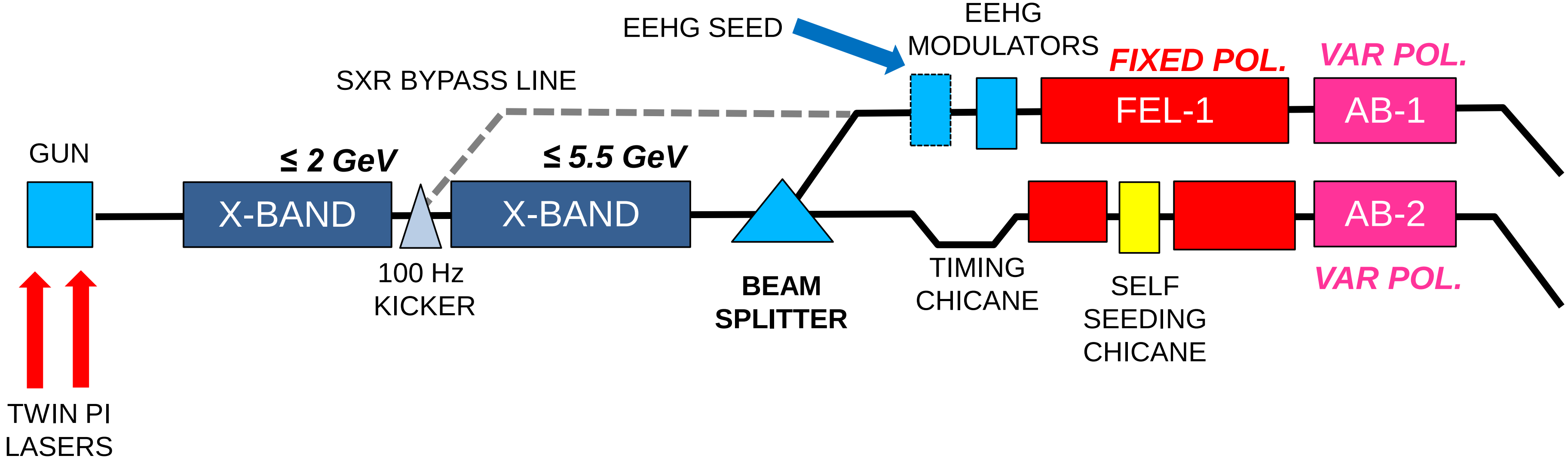
DESIRABLE USER REQUIREMENTS

- Stability
- Seeding at all wavelengths
- Pulse duration 0.1-1.0 fs in SXR
- Repetition rate 1kHz
- Simultaneous HXR/SXR operation
- Peak brightness 10^{33} ph/s/mm-mrad^2/0.1%bw at 16keV

UPGRADED MACHINE SCHEMATIC LAYOUT



ADDITIONAL OPERATING MODES

1. FEL-1 EEHG Seeded (or SASE) SXR and FEL-2 Self Seeded (or SASE) HXR combined for one experiment at 100Hz
2. FEL-1 EEHG Seeded (or SASE) SXR and FEL-2 Self Seeded (or SASE) HXR serving two independent experiments at 100Hz

Note:
Meets all of the Essential and Desirable Requirements

Parameters at the FEL

Parameter	Value	Comments	
Max Energy	5.5GeV @ 100Hz	• Allows options for undulator technology • Lower than SwissFEL	Consistent with Peak Brightness 10^{33} ph/s/mm^2/mrad^2/0.1%bw
Peak Current	5kA	• Achievable from LiTrack results	
Normalised Emittance	0.2 mm-mrad		
Bunch charge	< 75pC	• Consistent with emittance	
RMS Slice energy spread	1e-4	• Slice length = one SASE spike length ($2\pi l_c$ ~ 0.3fs)	
Max Photon Energy	16keV		
FEL tuning range at fixed energy	X 2		
Peak Spectral Brightness @ 16keV	10^{33} ph/s/mm^2/mrad^2/0.1%bw		

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Beam Energies for Full Wavelength Range

Absolute energy spread and normalised emittance are assumed to be constant

Saturation length kept the same so peak current reduces as photon energy reduces

Parameter	Value					
Energy (GeV)	5.5	3.9	2.75	1.95	1.37	0.97
Minimum Peak Current	5kA	2.5kA	1.5kA	925A	650A	350A
Normalised Emittance	0.2 mm mrad					
Bunch charge	75pC					
RMS Slice energy spread	1.0e-4	1.4e-4	2.0e-4	2.8e-4	4.0e-4	5.6e-4
Photon Energy Range (keV)	16 - 8	8 - 4	4 - 2	2 - 1	1 - 0.5	0.5 - 0.25
FEL tuning range at fixed energy	X2					

WP2 - Deliverable 2.2 (31/12/19)

- **Task 2.2 -** The outcome of the previous task [FEL Photon Specification] will be used by FEL experts (working closely with WP3, 4, & 5) to define the FEL system, with the accelerator and undulator requirements that are needed to achieve the specification (electron energy, bunch charge, peak current, emittance, energy spread, period, field strength, etc.). Then the task will identify and **choose the most appropriate technical solutions considering cost, technical risk and performance.** ***The other WPs make recommendations for all the technical solutions which are then agreed within this task.***
- **Deliverable 2.2** - A report summarising the FEL design, with the accelerator and undulator requirements to achieve the specification, i.e. electron energy, bunch charge, peak current, emittance, energy spread, undulator parameters, etc.
- Task Leader – Simone DiMitri

- This report is planned to be a **top level summary** of the facility layout, the associated parameters, and technical solutions selected – it is not a CDR!

WP2 - Deliverable 2.2 (31/12/19)

Implications for WP 3, 4, 5, 6

- By the end of 2019 all major **technical decisions** for the facility are expected to be made on the basis of cost, performance and technical risk
  - Choice of gun type, undulator technology, etc
  - To give us time to write the report, this really means taking firm decisions by end November (at our next face to face meeting?).

- To achieve this goal we **should not** be making any **major changes** to the electron parameters and layout after the Helsinki meeting.

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Thank you!

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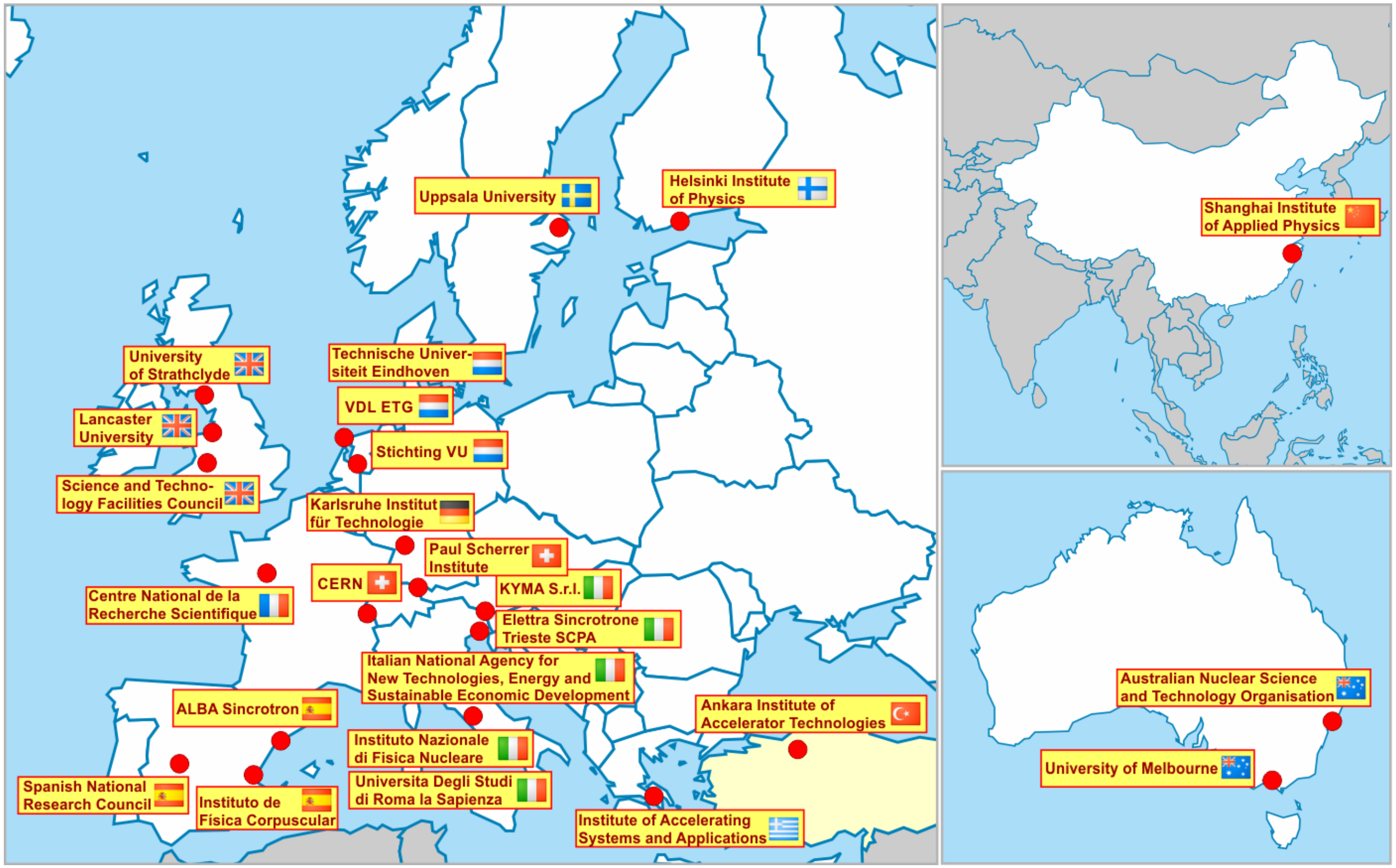

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