Permanent Magnet undulators

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- WP5 – PM Task. List of participants:

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WP5 tasks and deliverables

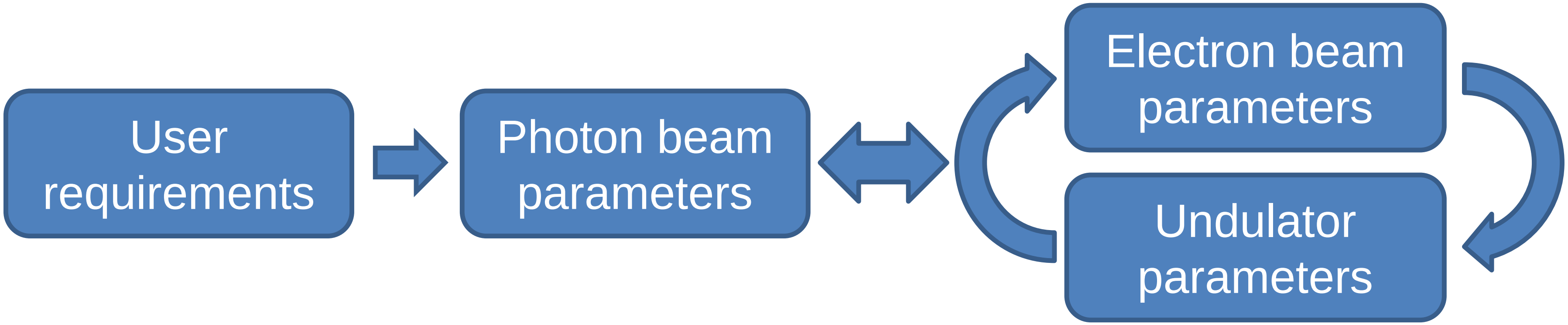
Task 5.1 - Review the technology trends for undulators R&D worldwide, and compare the potential for innovation and performance. In particular: superconducting undulators enabling field amplitude adjustment along the undulator (equivalent to the tapering of permanent magnet undulators), enhanced-bandwidth FEL radiation or super-radiant light sources at short wavelengths.

Task 5.2 - Select a few outstanding options to be considered for CompactLight.
Task 5.3 - For the options selected in T5.2, perform a systematic optimization of the electron beam parameters at the linac-to-undulator interface to maximise the photon production, in close contact with WP2 and WP6.

Task 5.4 - Report the conceptual design of the selected options as resulting from T5.3.

Description of deliverables
D5.1: A report comparing the different technologies for the undulator, as an input for WP2, (R, PU, M18). D5.2: Design Report of the undulator to be included in the main deliverable of CompactLight, (R, PU, M36). D5.1 : Technologies for the CompactLight undulator [18] Review report comparing the different technologies for the CompactLight undulator. D5.2 : Conceptual Design Report of the undulator [36] Design Report of the undulator to be included in the main deliverable of CompactLight

- Design of undulators



Undulator scenarios

Hard X-ray case

Undulator parameters	
undulator period	1-1.6 cm
undulator gap	3-8 mm
deflection parameter (RMS)	0.9-1.8
Bunch parameters	
beam energy	5-8 GeV
pulse duration (FWHM)	3-100 fs
bunch charge	10-100 pC
norm. emittance	0.5-1.5 mm×mrad
energy spread	0.01-0.08 %
Potential reach	
FEL wavelength	0.05-0.4 nm
N_γ/pulse	5×10^{10}-10^{12}
saturation length	30-70 m

Soft X-ray case

Undulator parameters	
undulator period	1.5-2.2 cm
undulator gap	3-8 mm
deflection parameter (RMS)	1.2-2
Bunch parameters	
beam energy	1-4 GeV
pulse duration (FWHM)	10-100 fs
bunch charge	10-80 pC
norm. emittance	0.6-1.6 mm×mrad
energy spread	0.01-0.08 %
Potential reach	
FEL wavelength	1-7 nm
N_γ/pulse	5×10^{11}-4×10^{12}
saturation length	15-45 m

F.Nguyen, WP2 meeting 2018-07-09

Any of these parameters needs to be revised/modified?

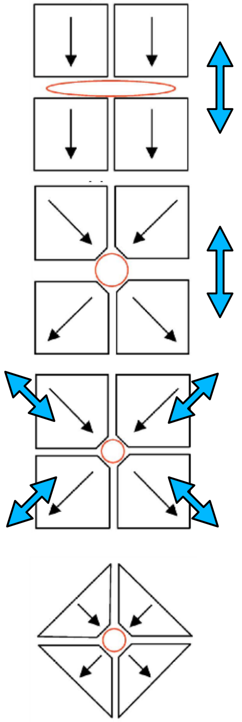
Funded by the
European Union

Compact

- # PM undulator architectures

Hard X-ray → Fixed polarization (?) → Planar devices → Room Temperature IVU / CPMU

Soft X-ray → Variable polarization → APPLE II / APPLE III / APPLE X / DELTA



APPLE II: gap/phase control

APPLE III: gap/phase control

APPLE X: independent radial adjustment for each array + phase control

DELTA: only phase control

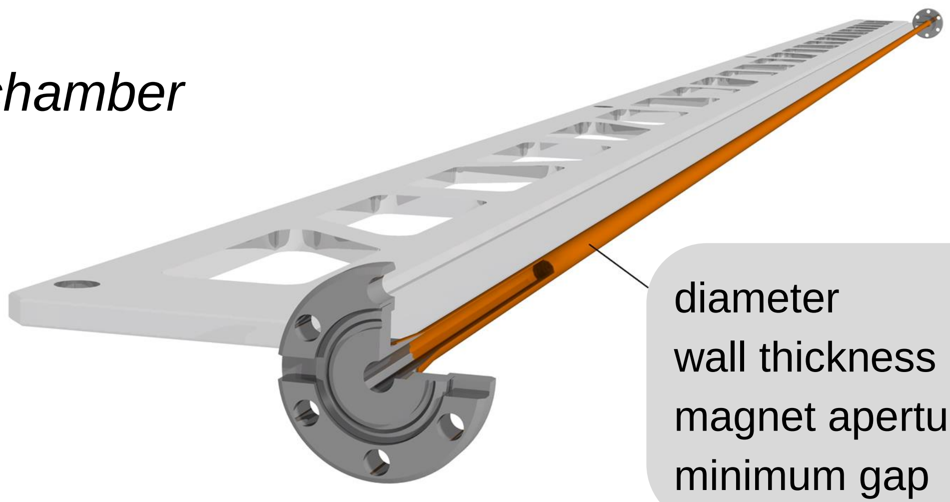
- PM undulator architectures
  - Hard X-ray

    - In principle no polarization control is required, so we can stick to simpler planar architectures.
    - In-vacuum technology is the standard for small gap planar PM devices.
    - Cryogenic PM undulators (CPMU) is becoming a mature technology, and it seems worthwhile using it given its benefits in terms of enhanced peak field value and increase of radiation resistance.
      - The price to pay is an increase in the complexity of the system, a more difficult magnetic characterization and higher running costs. However all these issues have already been addressed by other facilities.

PM undulator architectures

- Soft X-ray
  - No APPLE or DELTA-type in-vacuum undulators have been manufactured yet and doing so would be an engineering challenge
  - Therefore it would be desirable to confirm that it is feasible using out-of-vacuum solutions, even if it involves using ultra narrow vacuum chambers

Ultra thin vacuum chamber developed at PSI
(courtesy T. Schmidt)



diameter	5.0mm
wall thickness	0.2mm
magnet aperture	6.5mm
minimum gap	3.0mm

  - It has to be determined if a simple APPLE II configuration would fulfill polarization flexibility requirements or if a more complex APPLE X configuration is needed

PM undulator SWOT analysis

STRENGTHES	WEAKNESSES
• Low cost • Low energy consumption • Simple infrastructure • Well-known technology • Automated assembly procedure • For soft x-ray with full polarization and (with the APPLE X) gradient control	• Magnets demagnetization: at small gaps, possible heating form the beam with risks of local demagnetization (risk reduced in the case of CPMUs) • Limited field strength (but still with expansion options by new materials i.e. Tb diffusion especially for short period IVUs) • Issues with multipolar terms at very small gaps (minimized for single-pass machines)
OPPORTUNITIES	**THREADS**
• Verify the lowest period achievable with NC technology • Study of PPM magnet-holder new assembly techniques (soldering, gluing etc) • Development of automated procedure for serial production	• Achievement of the parameters required by CompactLight

R.Geometrante, WP5 meeting 2018-04-18

• PM undulator design: scaling laws

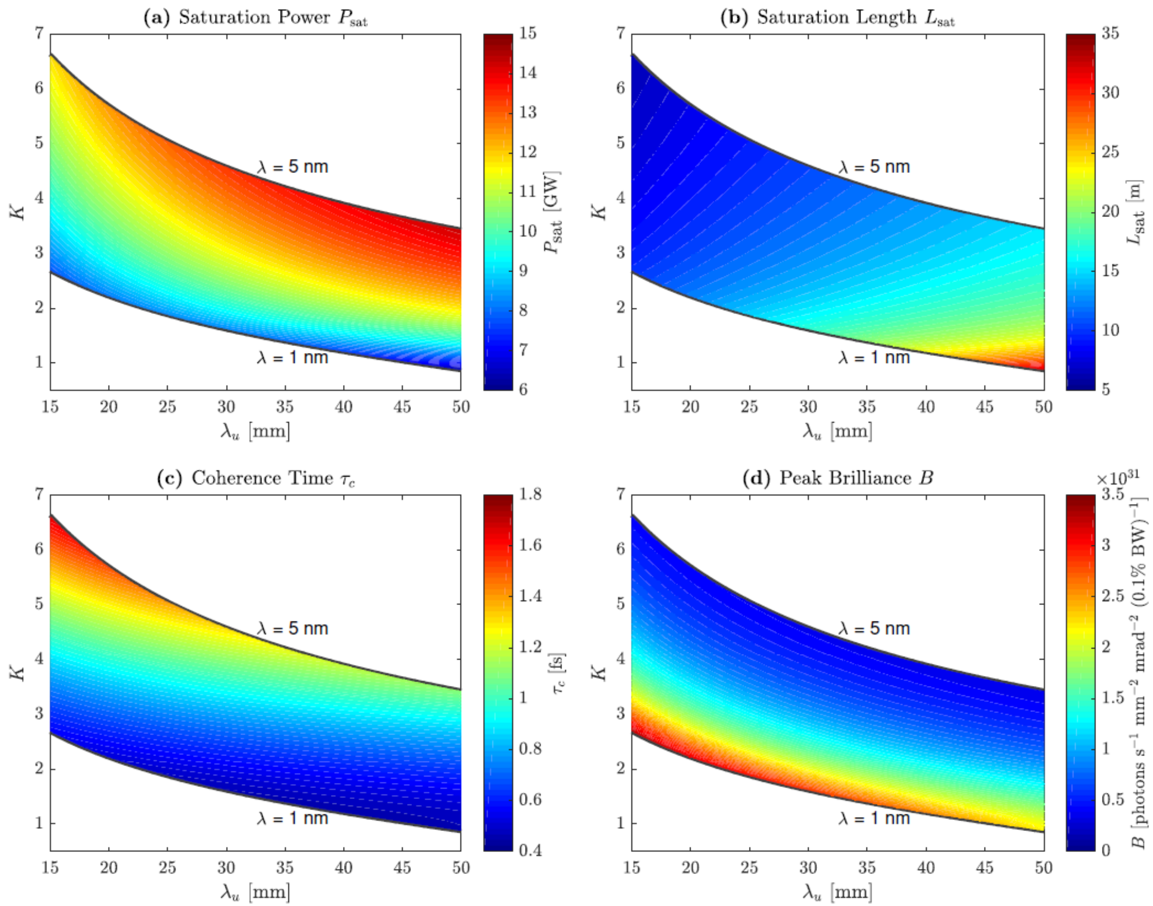


Figure 2: Colourmaps showing the variations of the four following parameters over the K-λ_u plane, in the region corresponding to the wavelength range of λ = 1–5 nm: (a) saturation power P_{sat}, (b) saturation length L_{sat}, (c) coherence time τ_c at saturation and (d) peak brilliance B at saturation.

- Study for MAX IV Soft X-Ray laser
- FEL parameters determined from Ming Xie parametrization

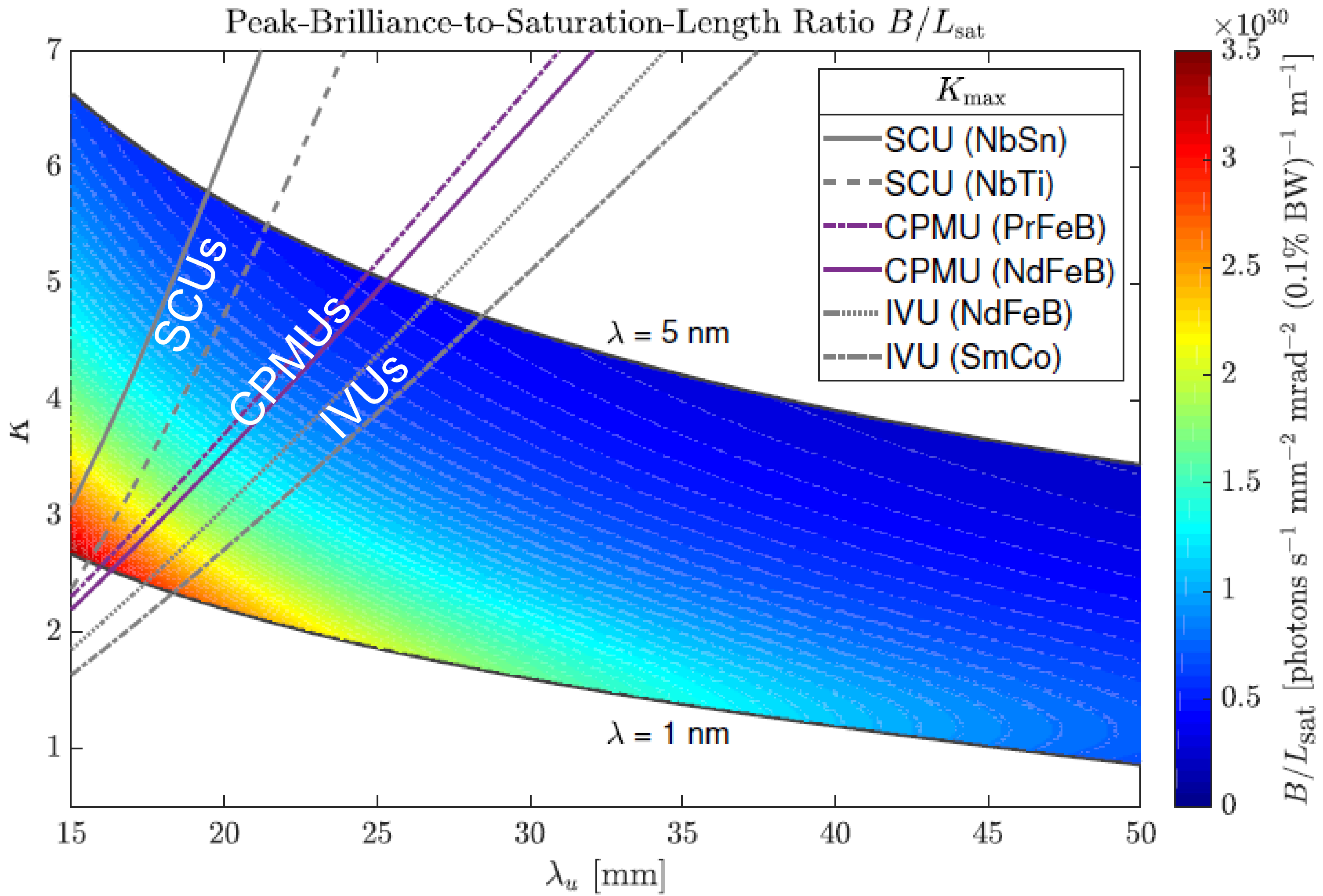
Table 2: Electron parameters in the case under study

Parameter	Symbol	Value
Electron energy	$\gamma m_e c^2$	3 GeV
Relative energy spread	σ_γ/γ	10^{-4}
Peak current	I_0	1.4 kA
Normalized emittance	ϵ_n	0.4 mm mrad
Average of beta function	$\bar{\beta}$	5 m

A.Mak, P.Salen, V.Goryashko, *Undulator Considerations in the Baseline Design of the MAX IV Soft X-Ray Laser*. Download from http://uu.diva-portal.org

- PM undulator design: scaling laws

K_{max} vs undulator period lines assuming a certain value for **minimum gap**



A.Mak, P.Salen, V.Goryashko, *Undulator Considerations in the Baseline Design of the MAX IV Soft X-Ray Laser*.
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- PM undulator design: next steps
  - Define a balance between the different driving conditions:
    - Compactness
    - Feasibility
    - Cost
    - State of the art
    - Aggressive solutions
  - Previous balance will have an impact on parameters such as minimum gap value, usage of in-vacuum/out-of-vacuum solutions, configuration for variable polarization devices, etc.
  - Look for two or three design alternatives for each energy range

Thank you!

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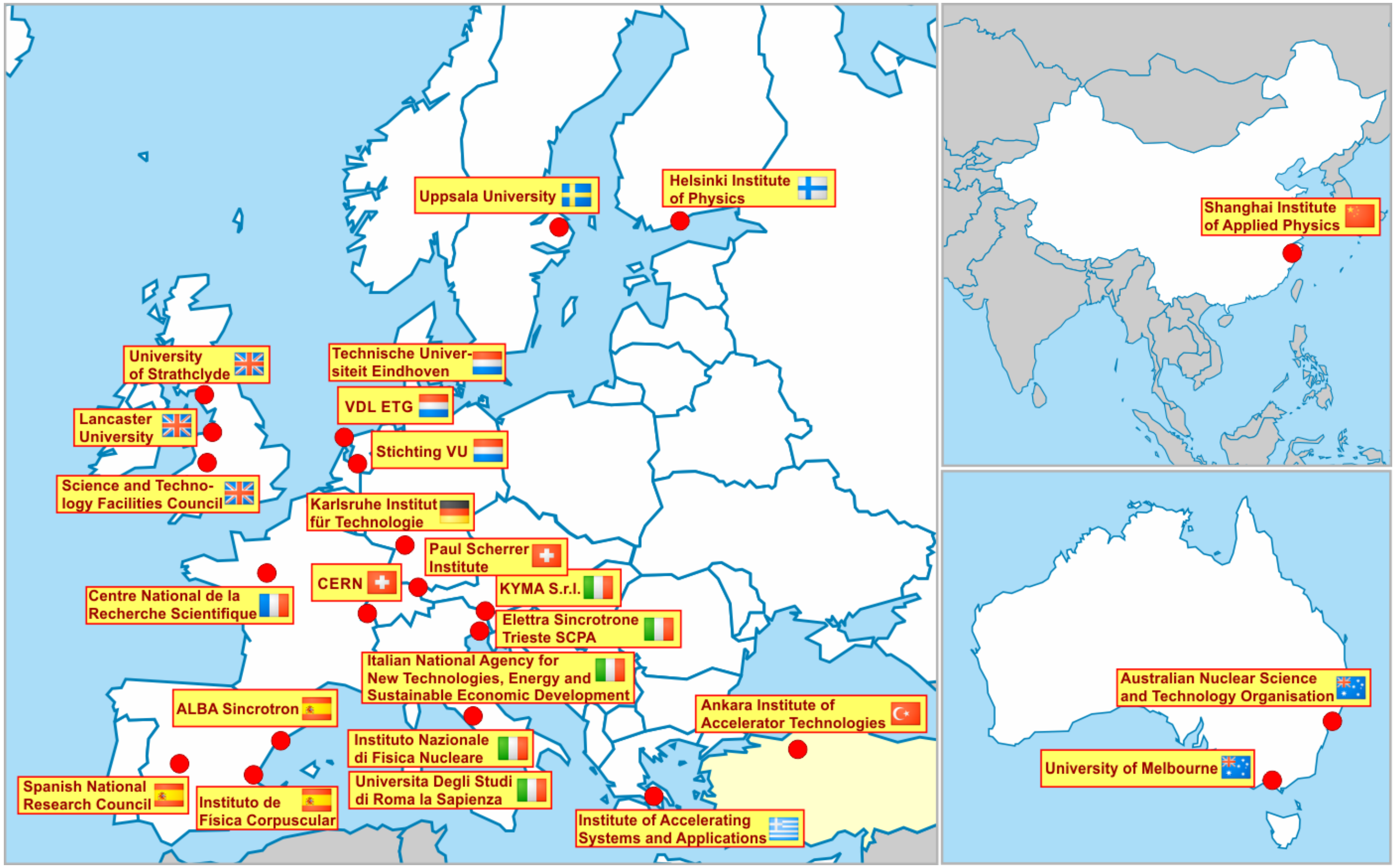

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