Feasibility Study for short period Undulators for the SASE4/5 Tunnels

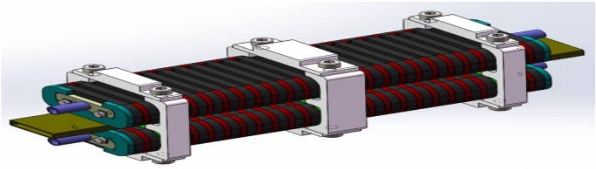
Content

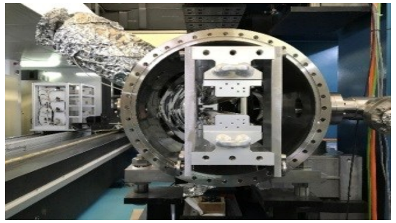
- Introduction, task description
- Field models for different types of undulators;
- Selection of fitting parameters
- Undulator parameter studies for the high photon energy FEL at the European XFEL
- Preliminary FEL simulations of 1^{st} and 3^{rd} Harmonic
- Summary

Introduction

- Problem: What is the suitable undulator technology for the super high (>= 50KeV) photon energies at EuXFEL?

- Content: Assessment and comparison of short period undulator technologies SC vs PM in VAC
  -> Focus on feasible technologies





Fitting formulae for the undulator peak field

PM

(Halbach, Nucl. Instr. Meth. 187(1981)
Journal de Physique 44, Colloque C1 (1983) 211)

$$B_{peak} = ae^{b\frac{g}{\lambda_u}+c\left(\frac{g}{\lambda_u}\right)^2}$$

- B_y is proportional to the magnet remanence, $a \propto B_r$
- PM systems are scalable; work for small dimensions as well

EM, SCU

(S. H. Kim, Nucl. Instr. Meth. A 546(2005))

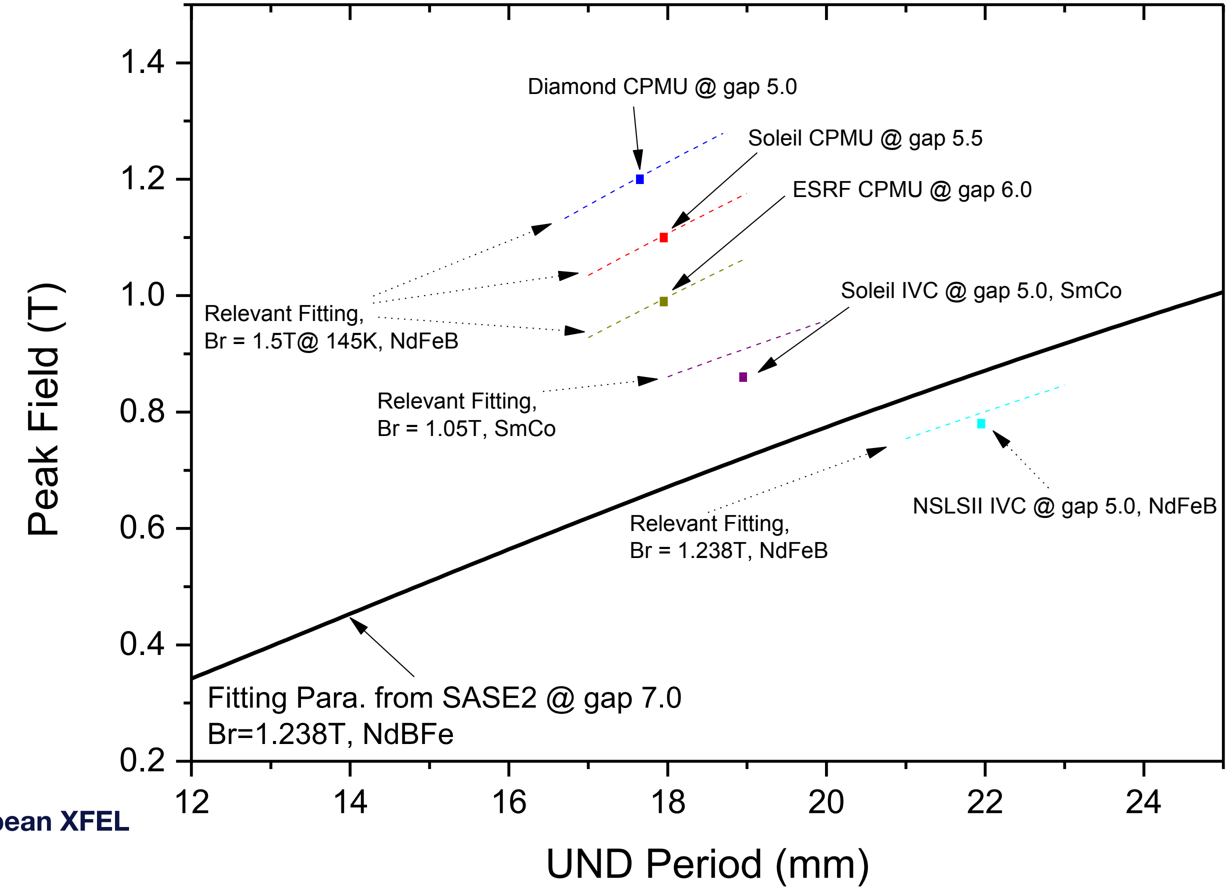
$$B_{peak} = (a + b\lambda_u + c\lambda_u{}^2 + d\lambda_u{}^3)e^{-\pi\left(\frac{g}{\lambda_u}-\frac{g_0}{\lambda_u}\right)}$$

- B_y is proportional to the current j_c times cross section
- B_y is scales $\approx\approx$ with $j_c\lambda_u$; the smaller λ_u the higher j_c !

Field model for Hybrid PM undulators

- Beam clear gap = 7mm → IVU magnet gap= Beam clear gap $g = 7mm$
- Fitting parameters taken from an optimized hybrid structure: EuXFEL U40 / SASE2

$$B_{peak} = ae^{b\frac{g}{\lambda u}+c\left(\frac{g}{\lambda u}\right)^2} \rightarrow a = 3.10487 \cdot \frac{B_r[T]}{1.238}, \quad b = -4.24914, c = 0.80266;$$



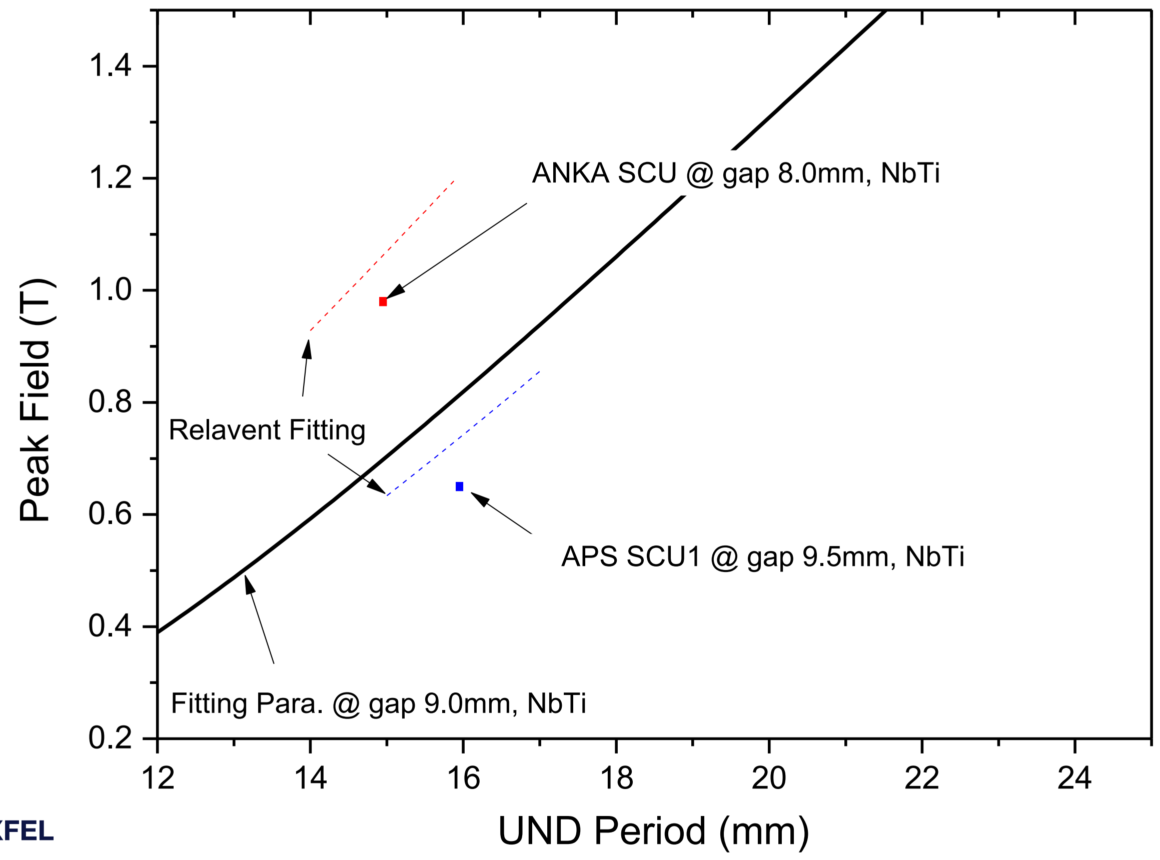
- The practical data of different UNDs from different labs agrees with the fitting curve quite good.

Field model for Superconducting undulators (SCU)

- Beam clear gap = 7mm → magnetic gap =beam clear gap + 2mm $g = 9mm$
- SCU using NbTi (data from G. Efim, $0.8j_c$ is used)

(S. H. Kim, Nucl. Instr. Meth. A 546(2005))

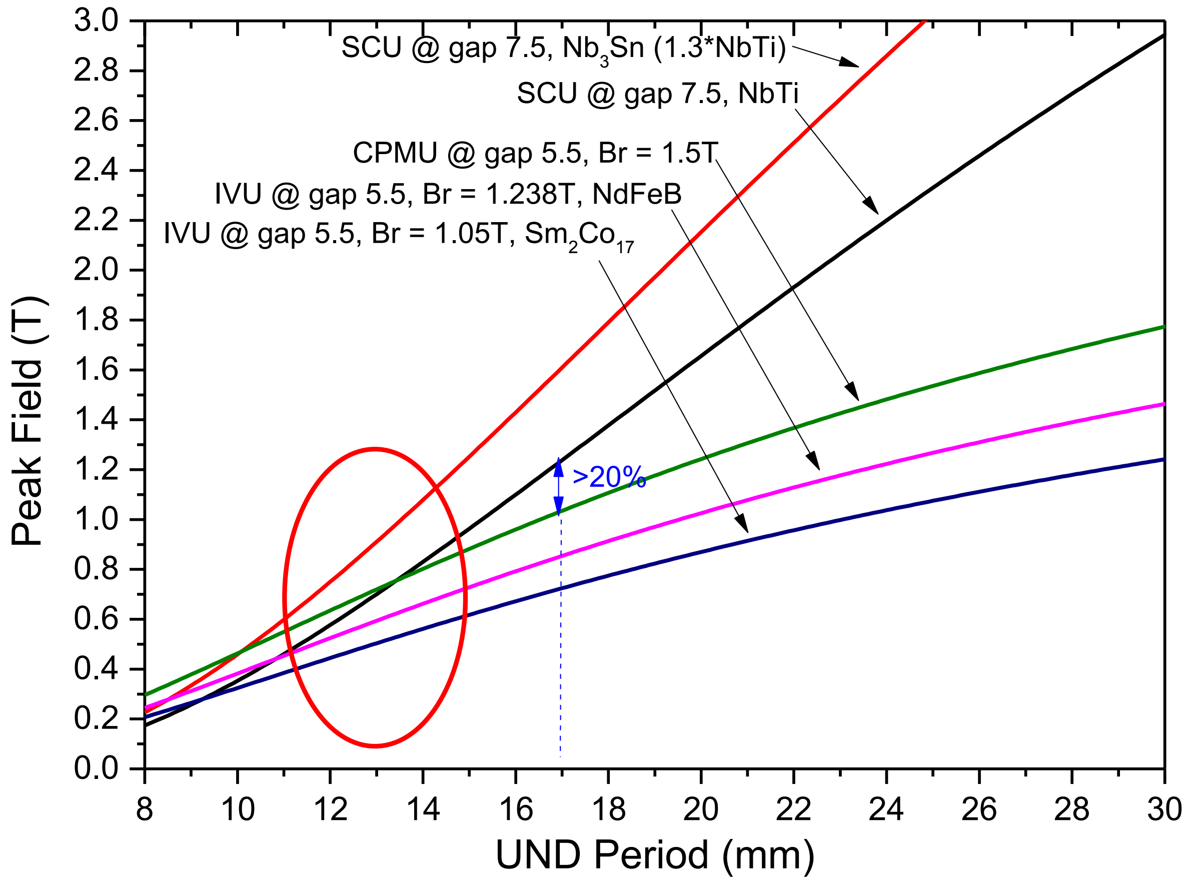
$$B_{peak} = (a + b\lambda_u + c{\lambda_u}^2 + d{\lambda_u}^3)e^{-\pi\left(\frac{g}{\lambda_u}-\frac{g_0}{\lambda_u}\right)} \rightarrow (0.28052 + 0.05798\lambda_u - 0.0009{\lambda_u}^2 + 5\times10^{-6}{\lambda_u}^3)e^{-\pi\left(\frac{g}{\lambda_u}-0.5\right)}$$

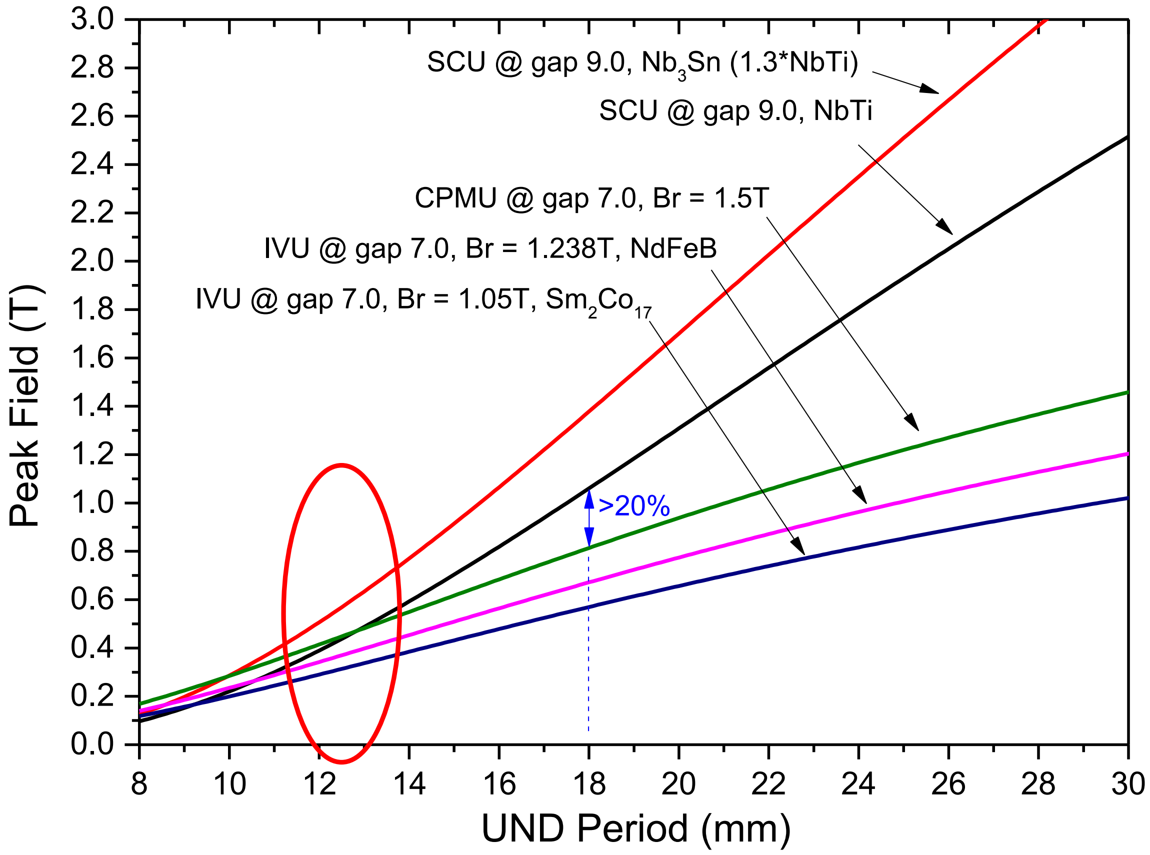


- Only two practical cases were found.
- The practical peak field is slightly smaller than the model.

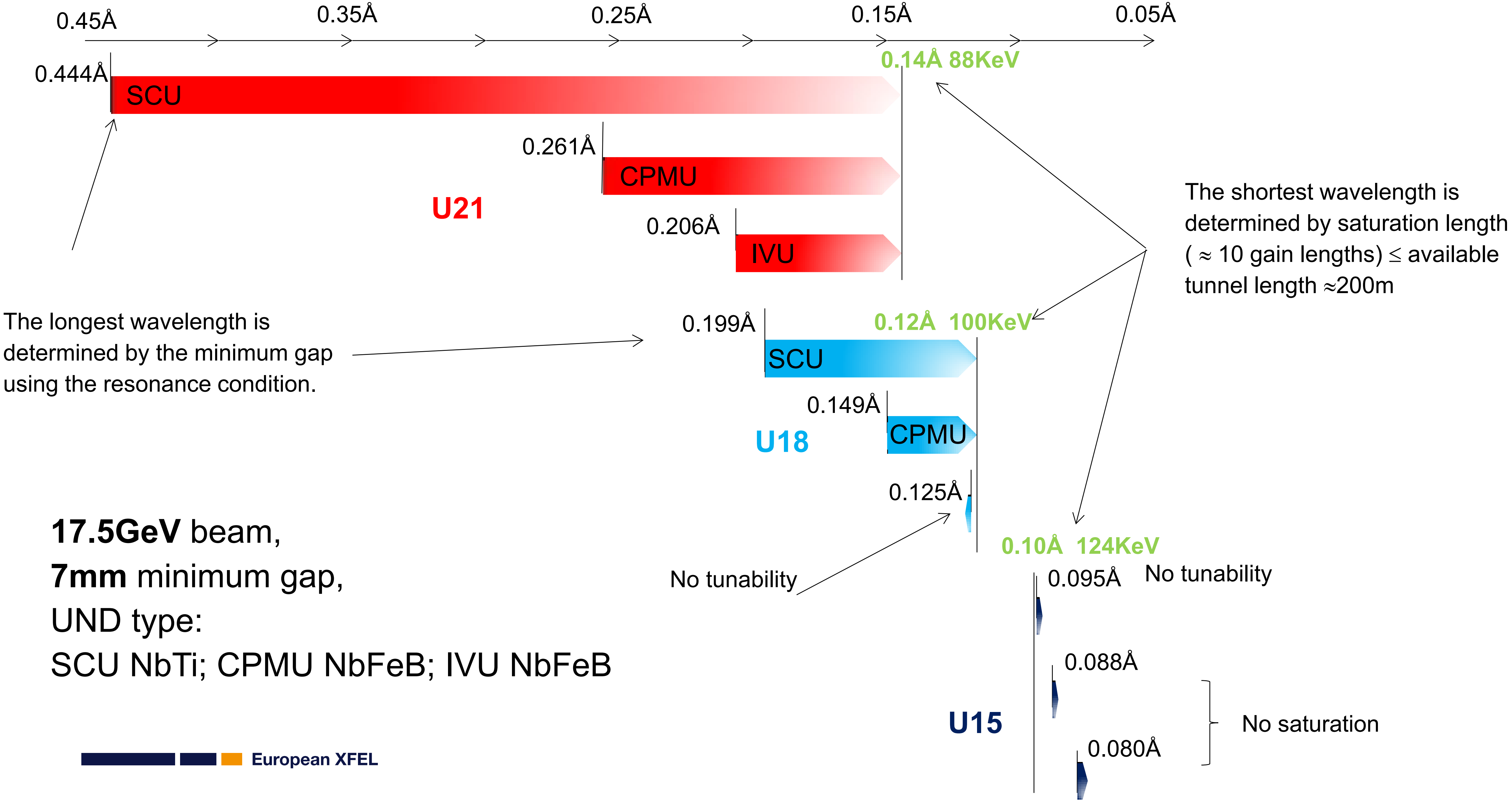
Comparison of the IVU and SCU

- The models are used for the comparison @ two gaps (5.5 mm VS 7.5mm) and (7mm VS 9mm)
- SCU shows clear advantages for NbTi only at the period longer than about 13 mm.





Tuneability



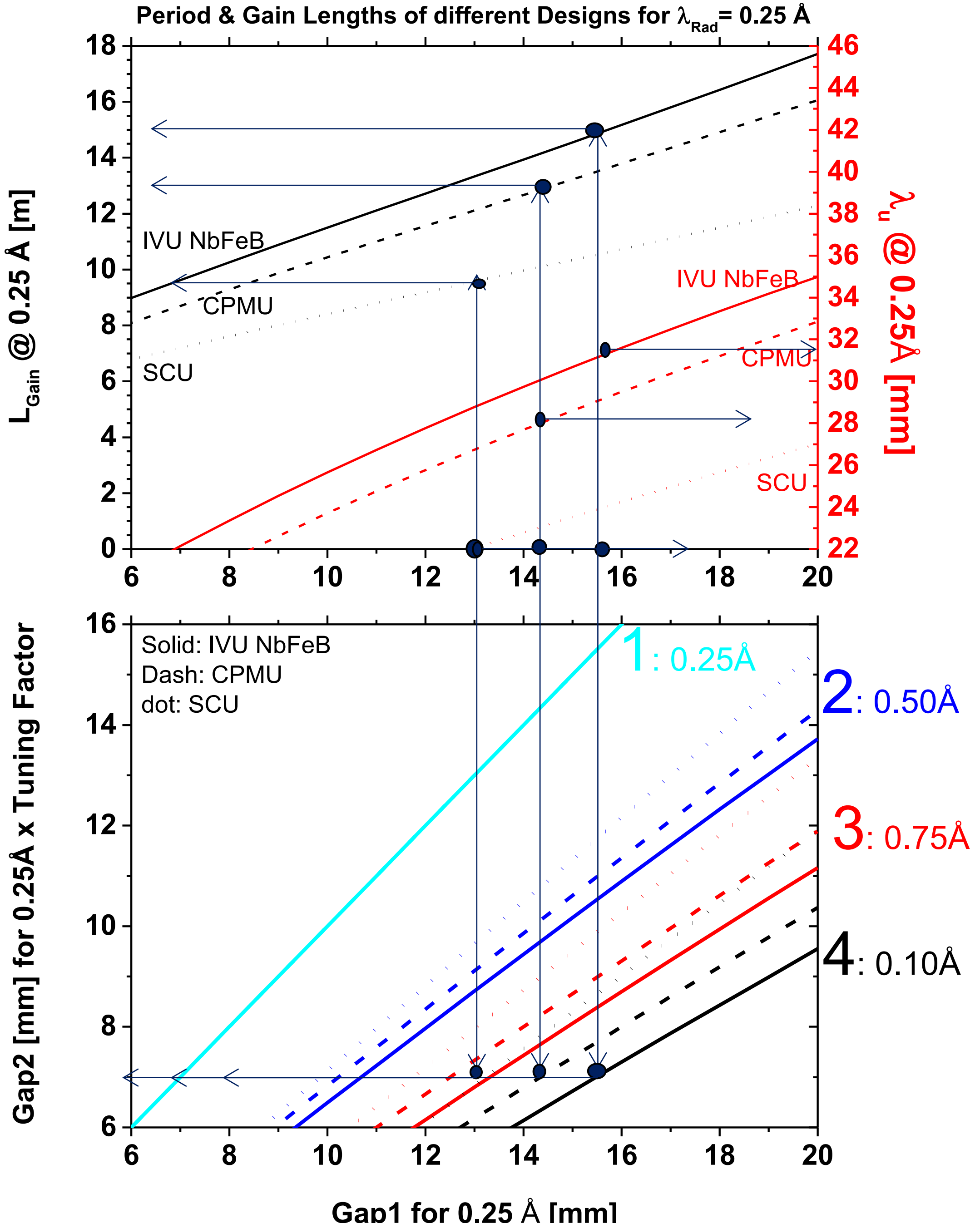
17.5GeV beam,
7mm minimum gap,
UND type:
SCU NbTi; CPMU NbFeB; IVU NbFeB

Target lasing @ 0.25 Å 50 keV

E = 17.5GeV
ΔE=1.5MeV
Peak current = 5000A
$\varepsilon_n = 0.4 mm\ mrad$

Example:
Minimum gap 7mm
Tuning factor 4, from 0.25~1.0 Å
IVU NbFeB, CPMU, SCU(NbTi)

0.25-1Å	IVU / NdFeB	CPMU	SCU (NbTi)
Large Gap [mm]	15.5	14.2	13
λ for 1Å @ 7mm [mm]	31.5	28	22
L_{gain} [m]	15	13	9.5

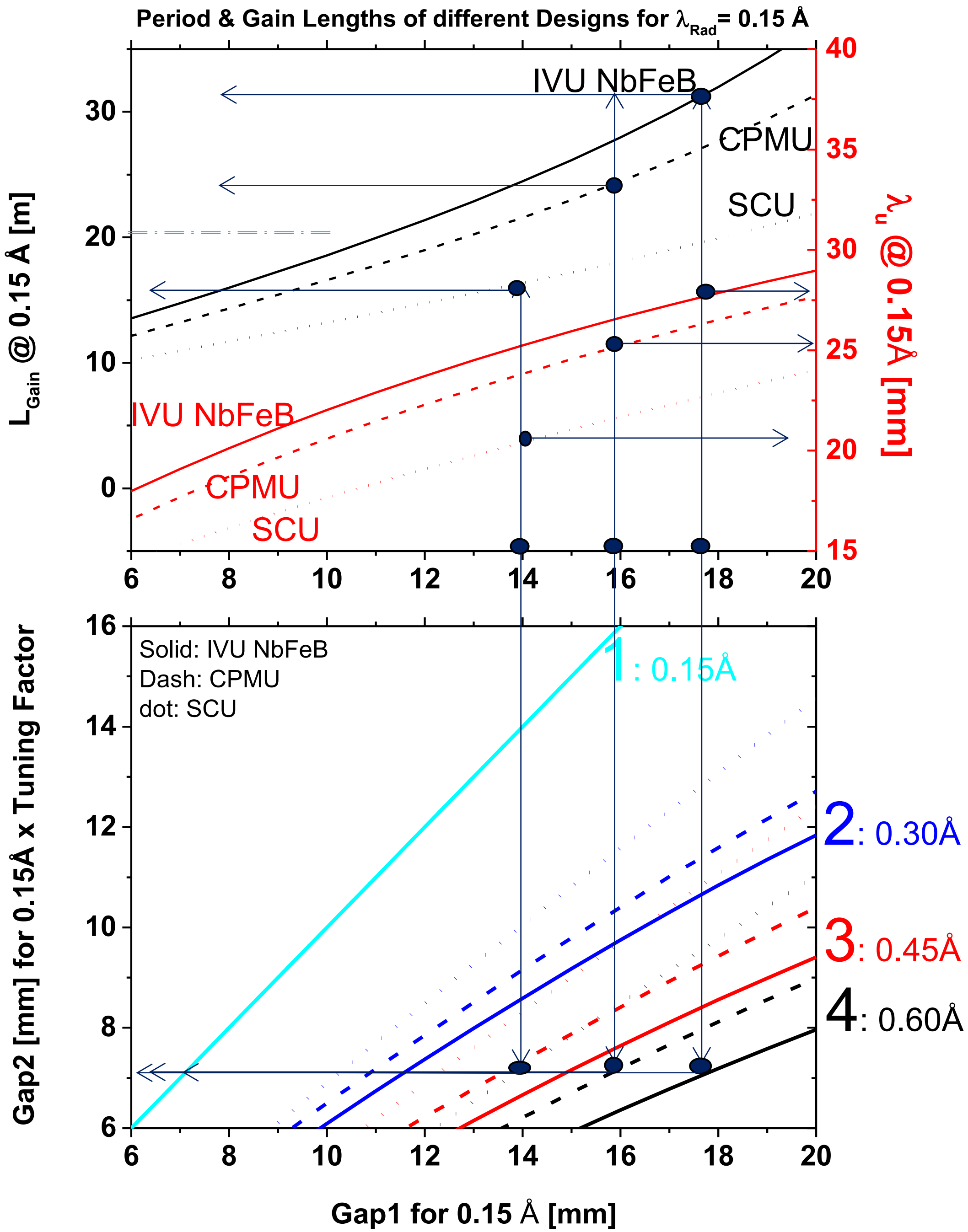


Target lasing @ 0.15 Å

E = 17.5GeV
ΔE=1.5MeV
Peak current = 5000A
$\varepsilon_n = 0.4mm\ mrad$

Example:
Minimum gap 7mm
Tuning factor 4, 0.15~0.6 Å
IVU NbFeB, CPMU, SCU(NbTi)

0.15-0.6Å	IVU / NdFeB	CPMU	SCU (NbTi)
Large Gap [mm]	17.8	15.9	14
λ for 0.6Å @ 7mm [mm]	28	25	20.5
L_{gain} [m]	32	25	15



0.15 Å Tuneability: 4 21….82 keV

0.15-0.6Å	IVU / NdFeB	CPMU	SCU (NbTi)
Large Gap [mm]	17.8	15.9	14 (K=3.43)
λ for 0.6Å @ 7mm [mm]	28	25	20.5
L_{gain} [m]	32	25	15

0.15 Å Tuneability: 2   41…. 82 keV

0.15-0.3Å	IVU / NdFeB	CPMU	SCU (NbTi)
Large Gap [mm]	11.6	11.0	10.2 (K=2.44)
λ for 0.3Å @ 7mm [mm]	23.5	21	18
L_{gain} [m]	20.5	16.5	13

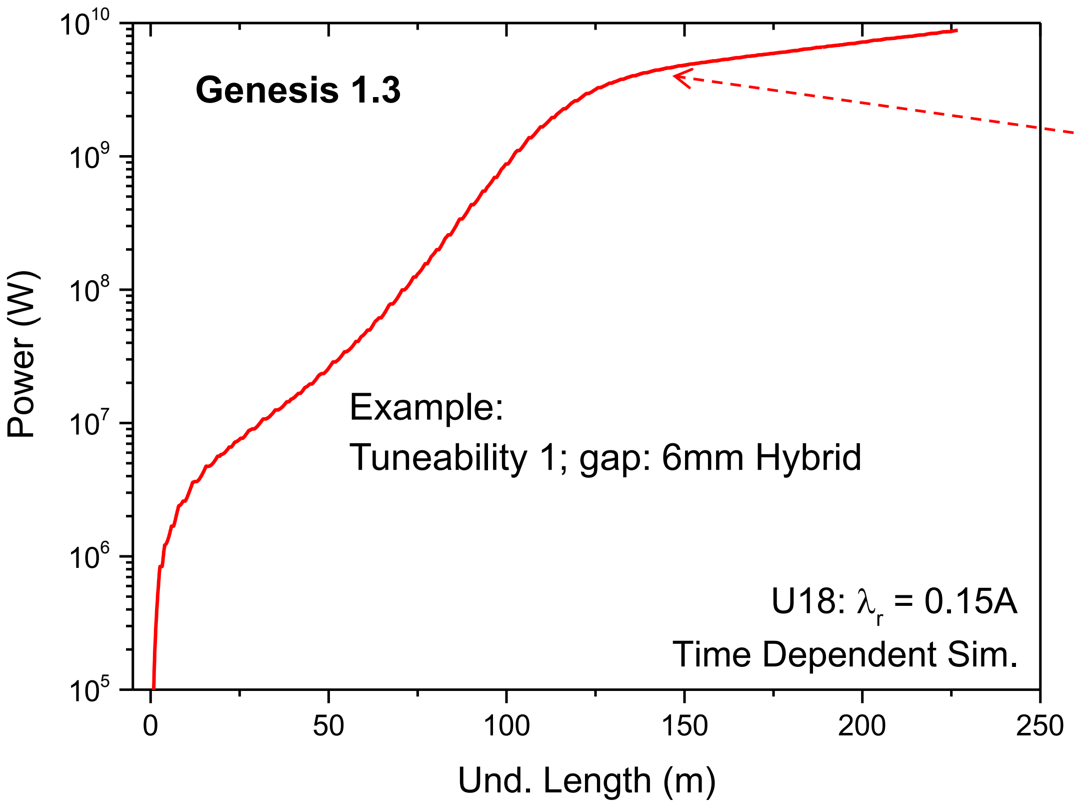
0.25 Å Tuneability: 4 12.4….50 keV

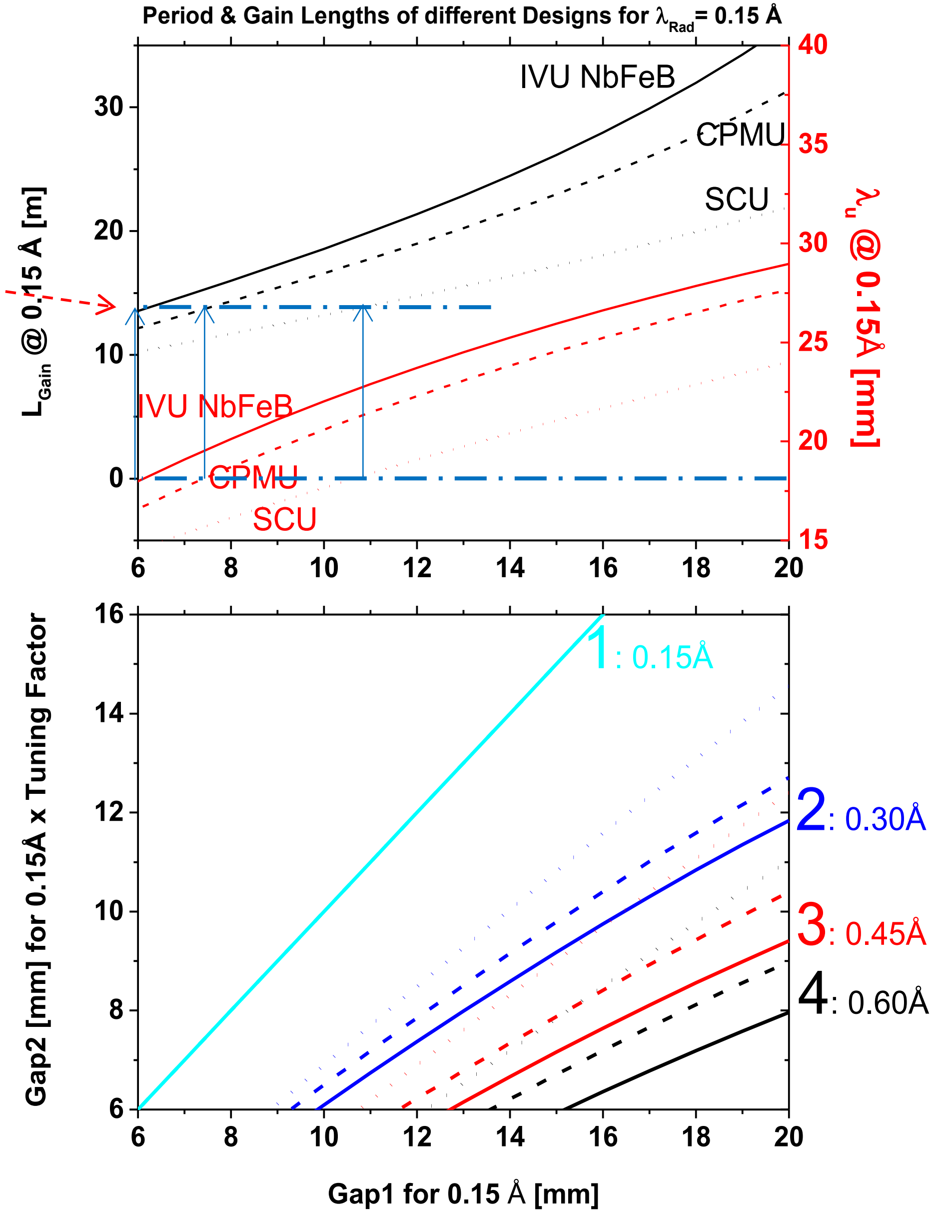
0.25-1Å	IVU / NdFeB	CPMU	SCU (NbTi)
Large Gap [mm]	15.5	14.2	13 (K=4.39)
λ for 1Å @ 7mm [mm]	31.5	28	22
L_{gain} [m]	15	13	9.5

0.25 Å Tuneability: 2 25….50 keV

0.25-0.5Å	IVU / NdFeB	CPMU	SCU (NbTi)
Large Gap [mm]	10.8	10.2	9 (K=3.15)
λ for 0.5Å @ 7mm [mm]	26.2	24	19.7
L_{gain} [m]	11.9	11.1	8.4

Gain curve of U18 @ 0.15 Å (fundamental)

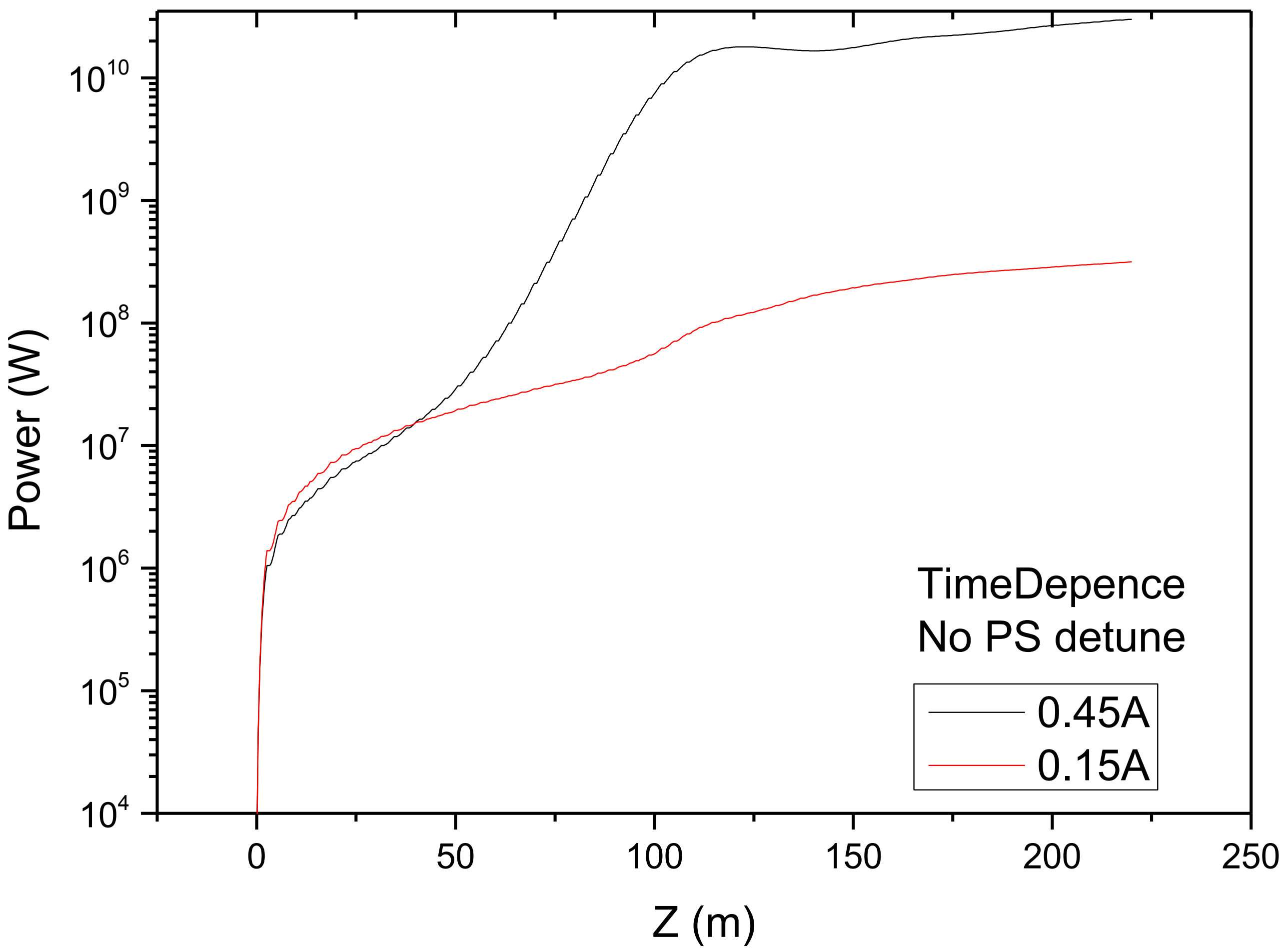




- Saturation length ~150m
- Saturation power ~ 5×10^9W

Fundamental and 3rd harmonic SASE of U40 @ 0.15 Å

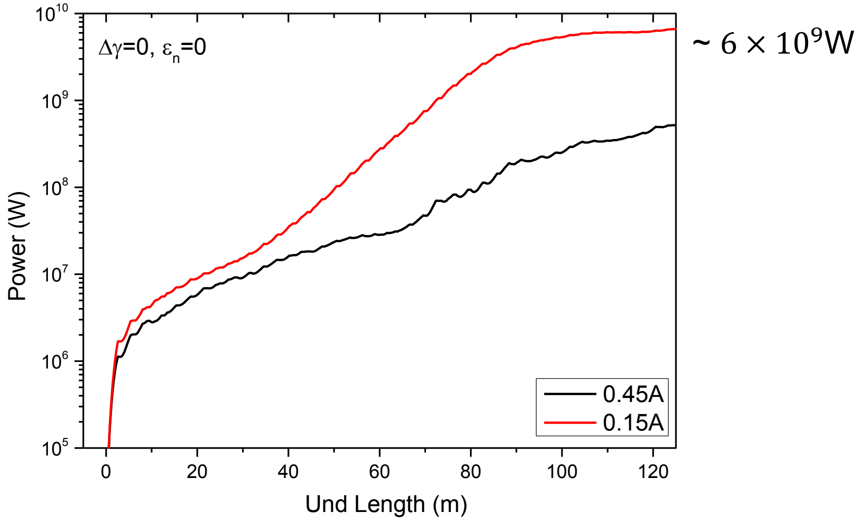
- Saturation length ~150m
- Saturation power of 0.15 Å ~ 2×10^8W
- Could be achieved with existing SASE2

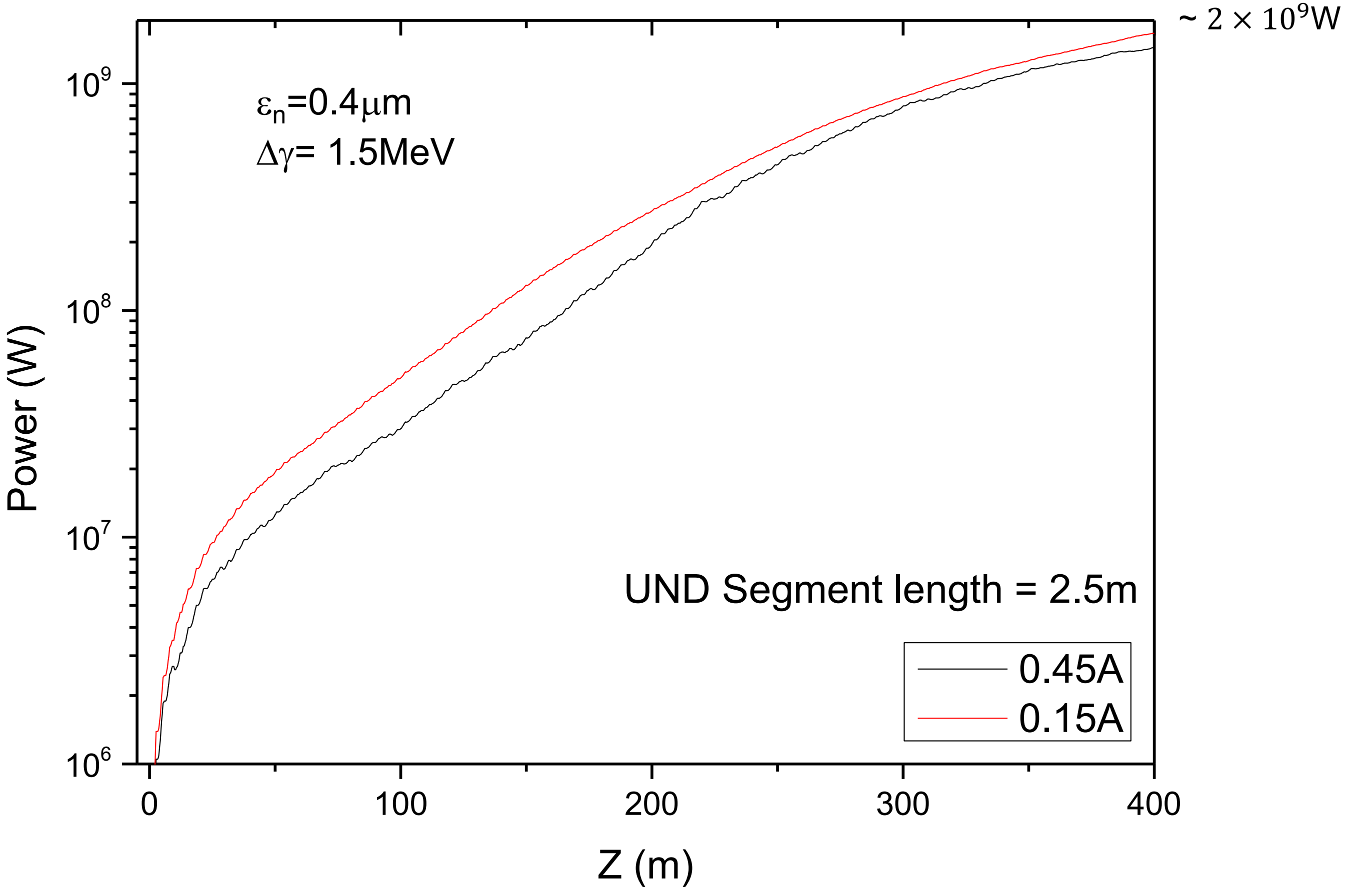


3rd harmonic SASE of U40 @ 0.15 Å by suppressing the fundamental

(E. Schneidrmiller, M. Yurkov, Phys. Rev. ST-AB 15(2012))

- Ideal beam with zero energy spread & emittance works well
- 3D simulation shows long saturation length ~400m
- Saturation power of 0.15 Å ~ 2×10^9W





Conclusion

- EuXFEL is a unique facility for a Hard X-ray FEL. About 80keV (0.15 Å) are feasible in the fundamental
- Tuneability requirements are important: 80keV, factor 1 only choice for NdFeB. Higher tuneability requires CPMU or SCU
  High tuneability, factor 4 requires SCU.
- SCU systems may be shorter by up to ≈ 40% compared to IVU, CPMU
- For given technology shortest wavelength and tuneability determine the undulator parameters.
  Shorter wavelength → lower tuneability → higher demands on field
- Using the non-linear harmonic SASE is promising:
  Existing SASE2 reaches $3x10^8$W at 0.15 Å. A dedicated U18 reaches $5x10^9$W: Needs more R&D: