PAUL SCHERRER INSTITUT

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FEL Scaling and Optimization

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FEL Optimization for Highest Photons Energies

FEL Performance depends on many parameter (wavelength range, energy, undulator type, emittance, energy epread, eurrent, focussing, available real estate, etc)

It is hard to optimize unless some limits are given:

- If a given energy is possible then any optimization will favor the maximum energy. Thus this can be considered as a given.
- Real estate is a hard limit similar to energy. Optimization for highest photon energies will always use the maximum length.
- Electron beam parameters value should be conservative which can be achieved on a regular basis

Any lower photon energy or better electron beam parameter will guarantee to perform better.

Undulator Model

It is better to express the undulator field by its RMS strength. That way there is only minimal difference between helical and planar undulator in the FEL model

$$\lambda = \frac{\lambda_u}{2\gamma^2}(1+a_w^2)$$

The undulator period and the field strength is related by the rms on-axis field

$$a_w = \frac{e}{2\pi mc}\lambda_u \cdot B_{rms}$$

It is best to assume a constant maximum field. This defines, depending on the type and design of the undulator, the gap.

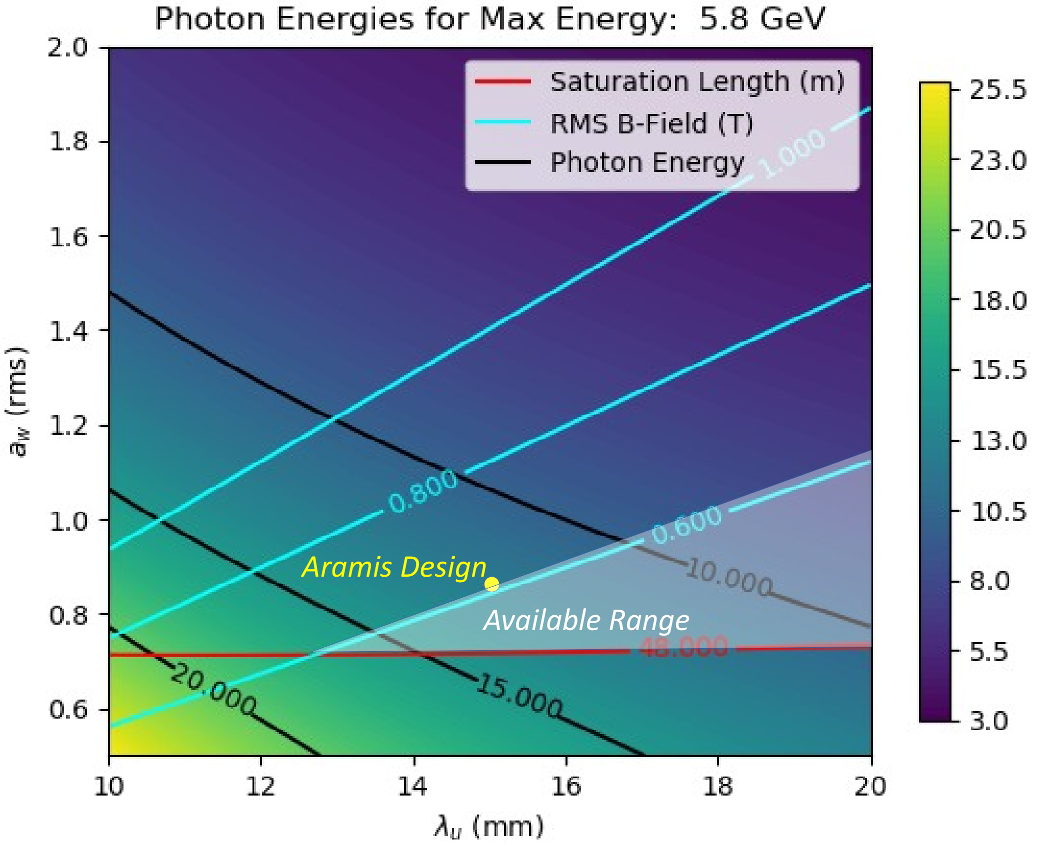
Example: Aramis

$$K = 1.2 \Rightarrow a_w \approx 0.85 \Rightarrow B_{rms} \approx 0.61 \text{ T}$$

Example: Aramis Design

E=5.8 GeV, I=3 kA, σ_E=0.35 MeV, ε_n = 430 nm

Maximum available length is 48 m.



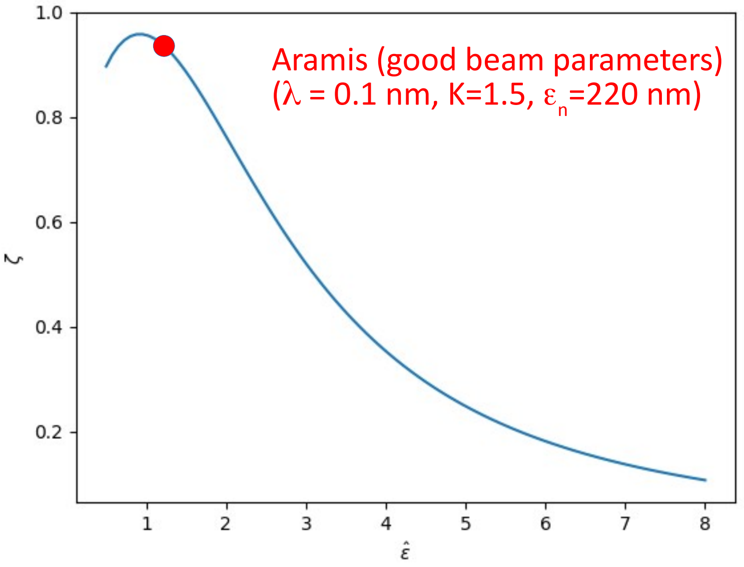
Coherence

To allow all electrons to radiate into a fundamental mode, following condition has to be fulfilled:

$$\frac{\epsilon_n}{\gamma} \leq \frac{\lambda}{2\pi} \Rightarrow \hat{\epsilon} \equiv \frac{2\pi\epsilon_n}{\gamma\lambda} \leq 1$$

The degree of coherence is then estimated with: [Saldin et al, Opt. Comm 281. (2008)]

$$\zeta \approx \frac{1.1\hat{\epsilon}^{1/4}}{1 + 0.15\hat{\epsilon}^{9/4}}$$

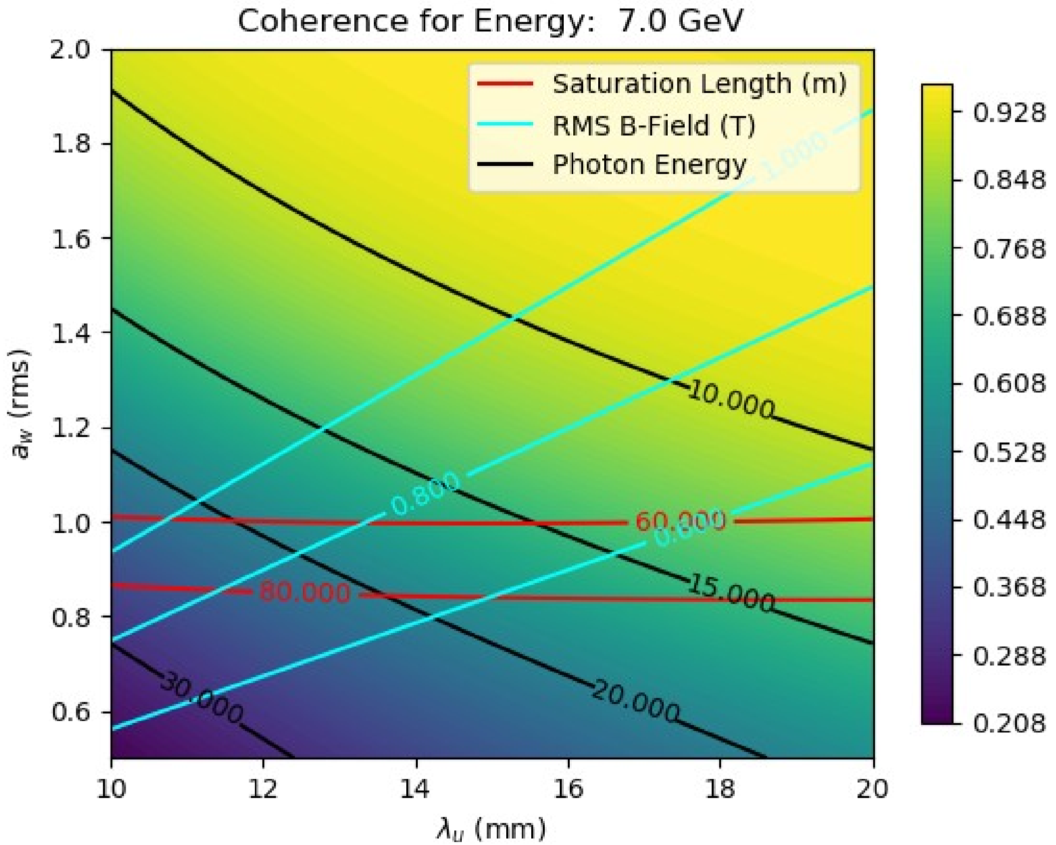


This is a rigid beam model. With electron motion and focusing it is relaxed by roughly a factor 2

Example at 7 GeV

E=7 GeV, I=1.5 kA, σ_E=1 MeV, ε_n = 400 nm

Effective Length of 60 and 80 m. Assuming 75 % filling factor as Athos, this corresponds to about 80 and 100 m physical length.



Comments:

1) With 20 mm period the highest photon energy will be 14 keV

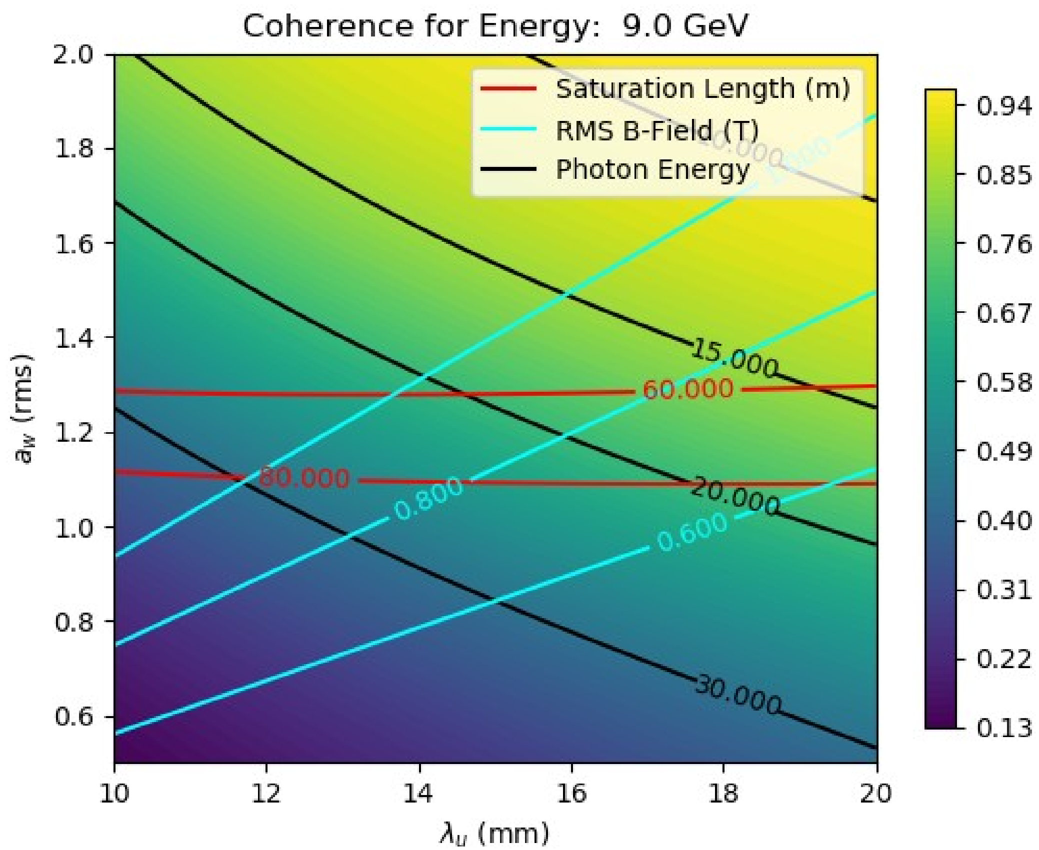
2) With 10 mm period, this highest photon energy is 25 keV but has poor coherence

3) Reasonable good coherence (>0.6) is at a photon energy of 20 keV or lower.

Example at 9 GeV

E=9 GeV, I=1.5 kA, σ_E=1 MeV, ε_n = 400 nm

Effective Length of 60m is more realistic since we have to give space to a larger linac.



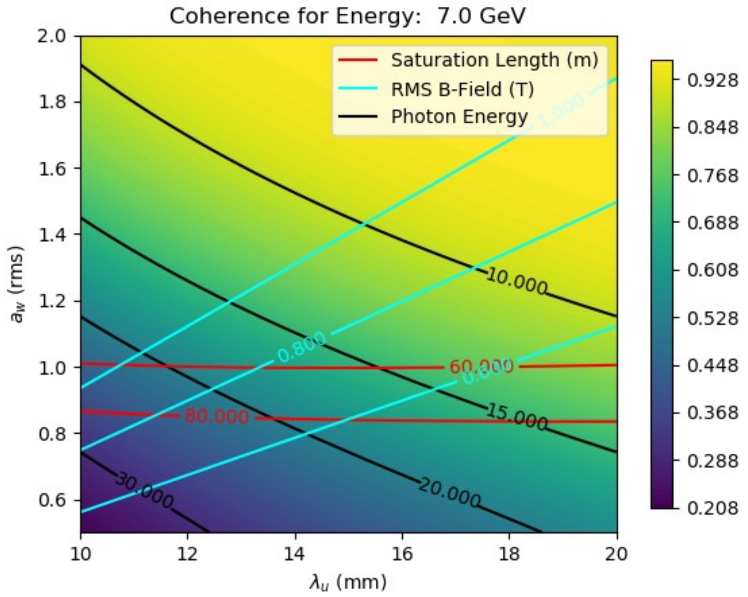
Comments:

1) With 20 mm period the highest photon energy will be 14 keV

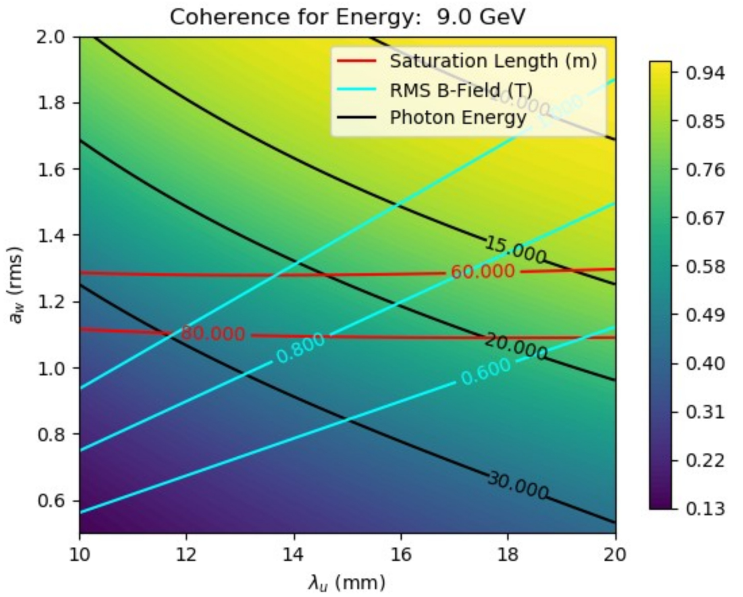
2) With 10 mm period, this highest photon energy is 30 but has moderate coherence

3) Reasonable good coherence (>0.6) is at a photon energy of 25 keV or lower.

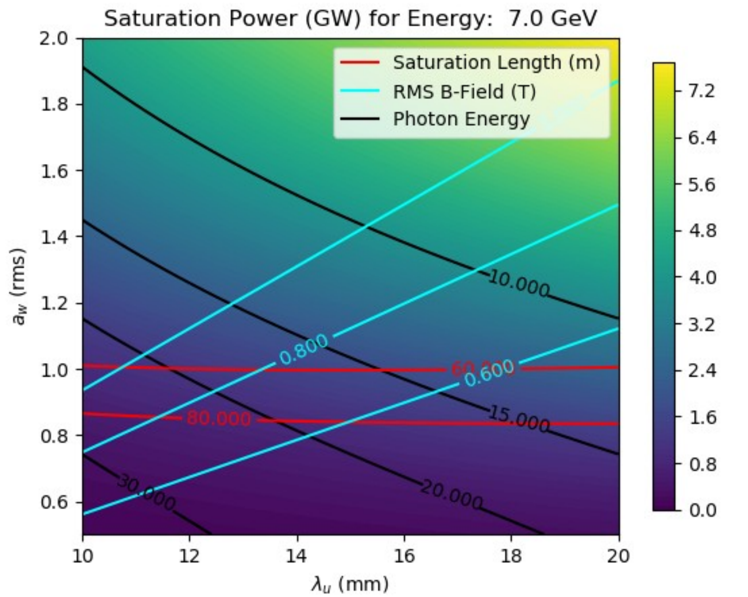
Comparison



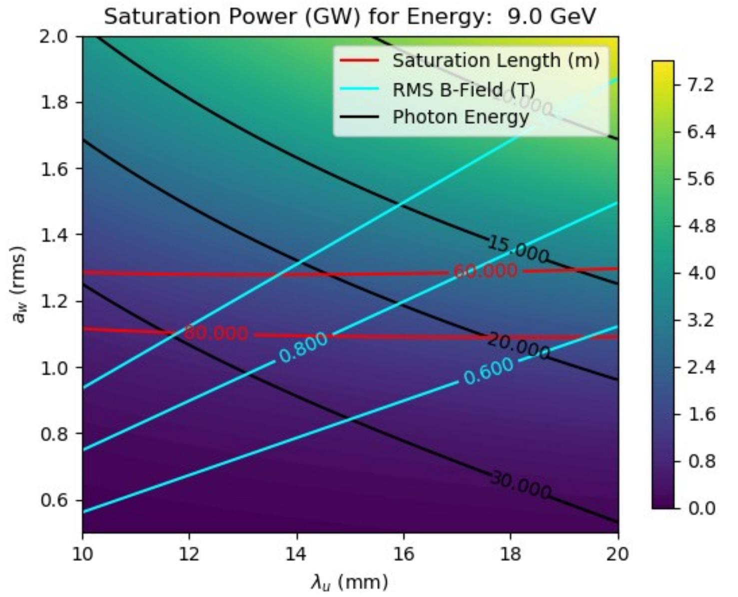
Coherence for Energy: 7.0 GeV
Saturation Length (m)
RMS B-Field (T)
Photon Energy
a_w (rms)
λ_u (mm)
10.000
15.000
20.000
30.000
60.000
80.000
0.800
0.600
1.000
0.928
0.848
0.768
0.688
0.608
0.528
0.448
0.368
0.288
0.208



Coherence for Energy: 9.0 GeV
Saturation Length (m)
RMS B-Field (T)
Photon Energy
a_w (rms)
λ_u (mm)
15.000
20.000
30.000
60.000
80.000
0.800
0.600
0.94
0.85
0.76
0.67
0.58
0.49
0.40
0.31
0.22
0.13



Saturation Power (GW) for Energy: 7.0 GeV
Saturation Length (m)
RMS B-Field (T)
Photon Energy
a_w (rms)
λ_u (mm)
10.000
15.000
20.000
30.000
80.000
0.800
0.600
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0



Saturation Power (GW) for Energy: 9.0 GeV
Saturation Length (m)
RMS B-Field (T)
Photon Energy
a_w (rms)
λ_u (mm)
15.000
20.000
30.000
60.000
80.000
0.800
0.600
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0

Main Conclusion

With 20 mm period, reachable photon energies are only slightly beyond Aramis with a limit of about 14 keV. For 7 GeV the performance (due to the low aw) is worse than Aramis. Only the possible choice of variable polarization and the larger tuning range without energy change makes this attractive

With 10 mm period higher photon energies are reachable (25-30 keV) but requires a huge increase increase of beam energy to overcome the drop in coherence

15 mm period seems to be a good compromise between maximum wavelength, saturation power and coherence.

Improving on the other parameters would help but seems unrealistic or a high risk to fail