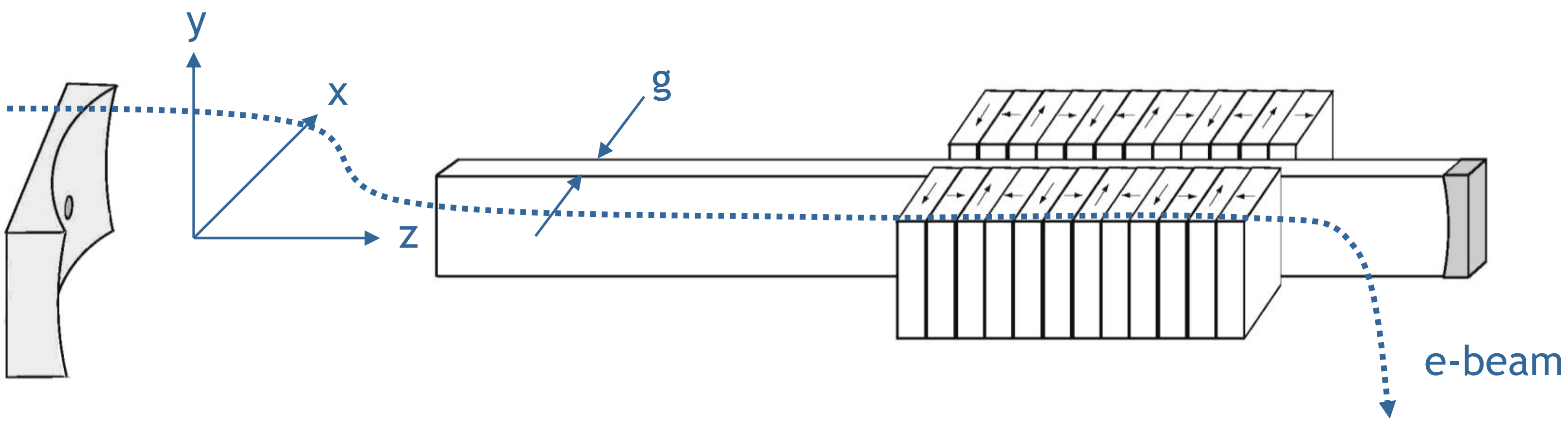
Tuning gaps in the FELIX long-wavelength FEL

Dick Oepts and Lex van der Meer

Partial-waveguide resonator

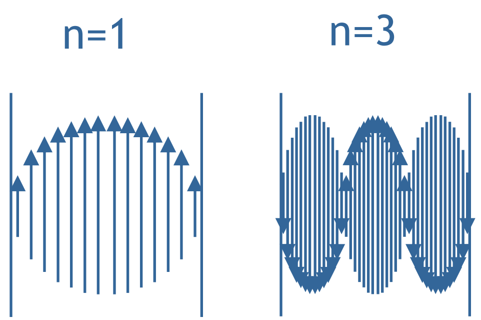


Eigenmodes are a combination of TE and Hermit-Gaussian modes:

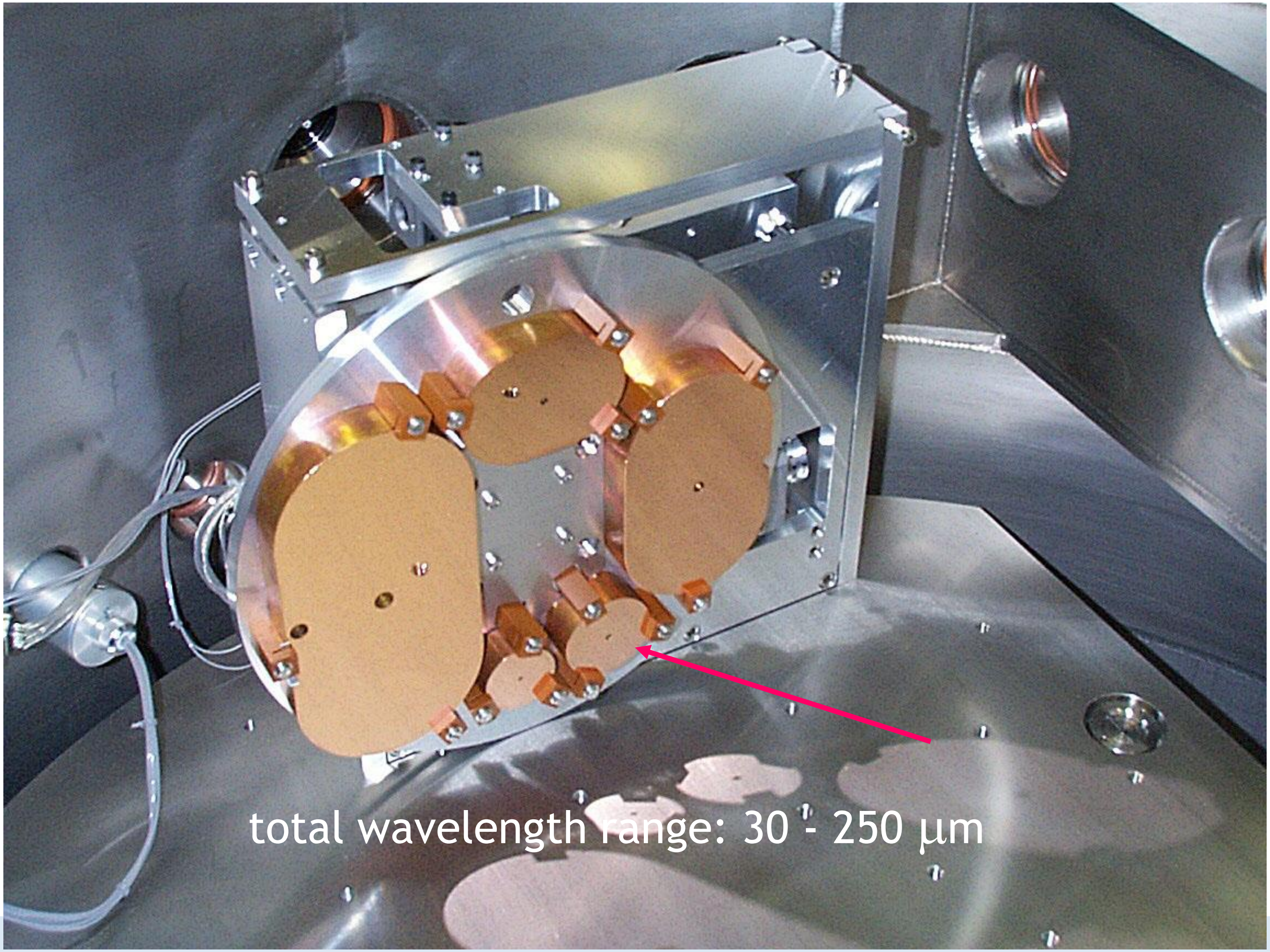
$$\Psi_n(x,y,z) = \cos\left(\frac{nx\pi}{g}\right)\exp\left(\frac{-y^2}{w^2(z)} + i\left(\frac{k_n^z y^2}{2R(z)} - \frac{1}{2}\tan^{-1}\frac{z}{z_r}\right)\right)$$

with $w(z) = w_0 \cdot \sqrt{1+\frac{z^2}{z_r^2}}$, $k_n^z = \sqrt{k^2 - n^2 k_\perp^2}$, $R(z) = z + \frac{z_r^2}{z}$

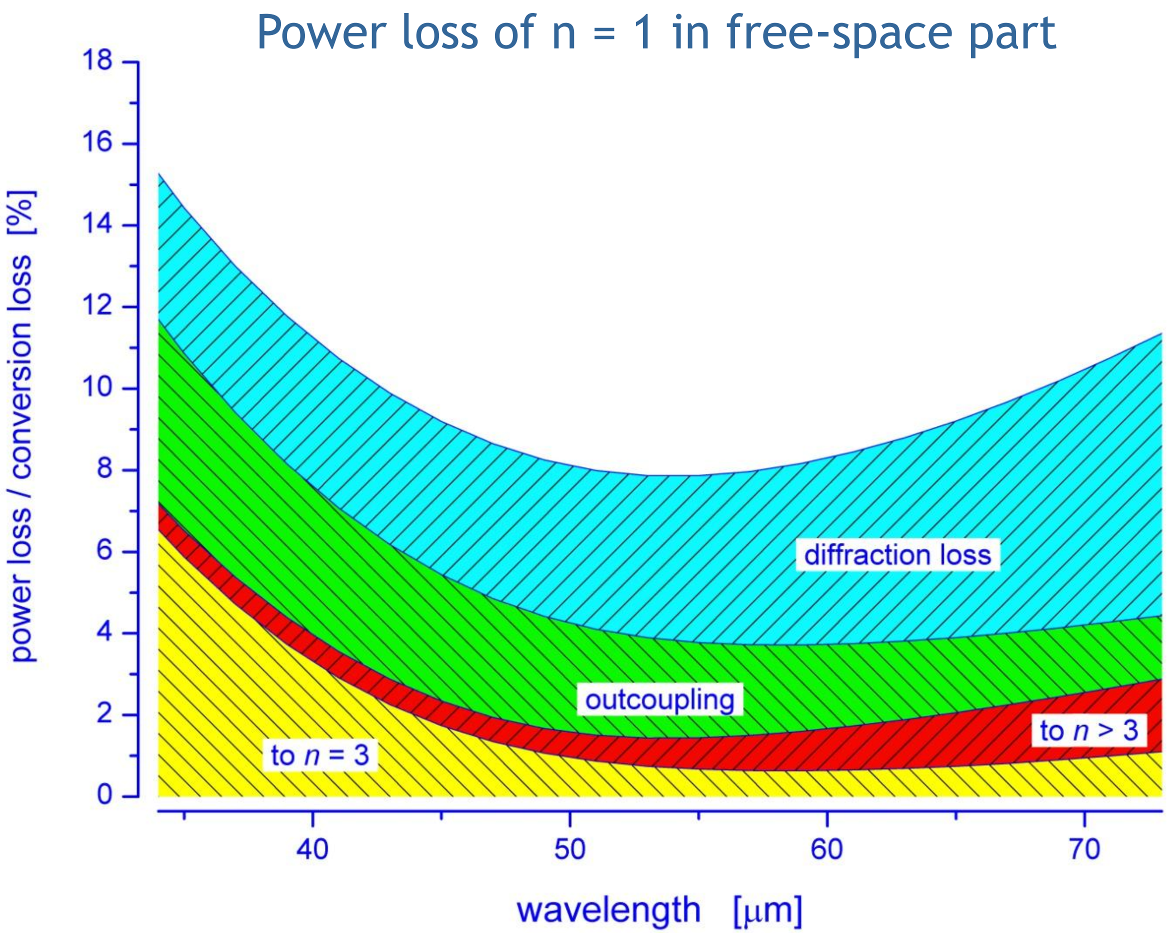
and $k_\perp = \frac{\pi}{g}$, where k is the wave vector in vacuum, z_r the Rayleigh range and w_0 the waist



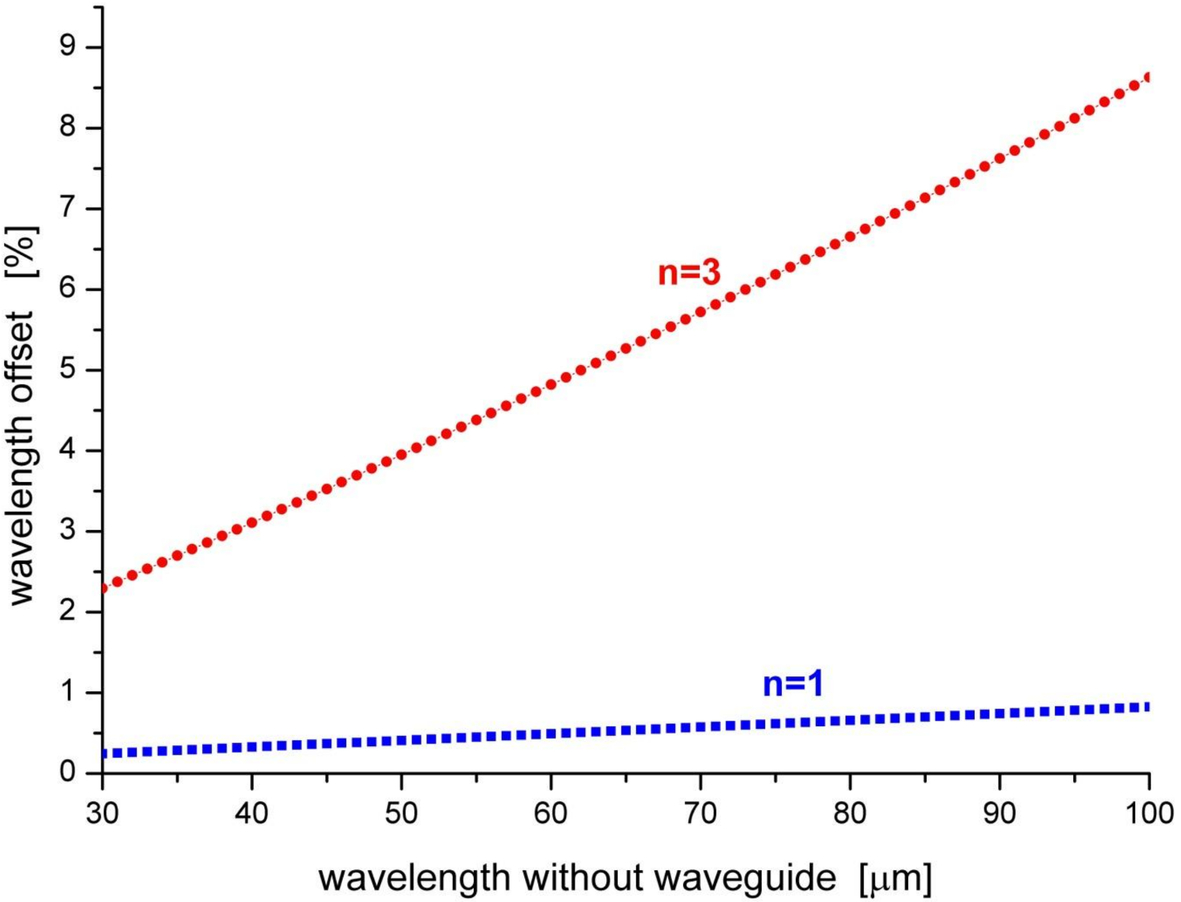
Mirror carousel



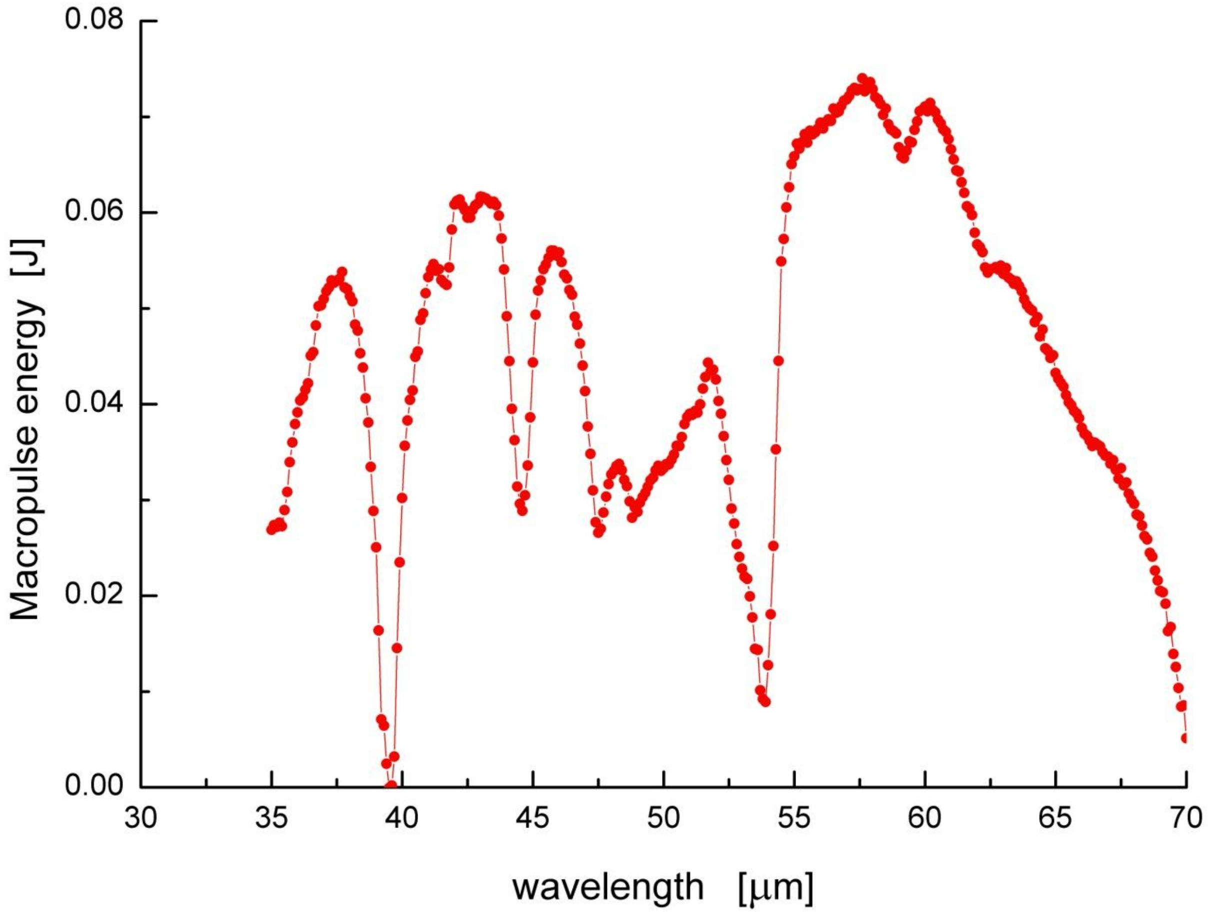
Mode conversion in free-space part



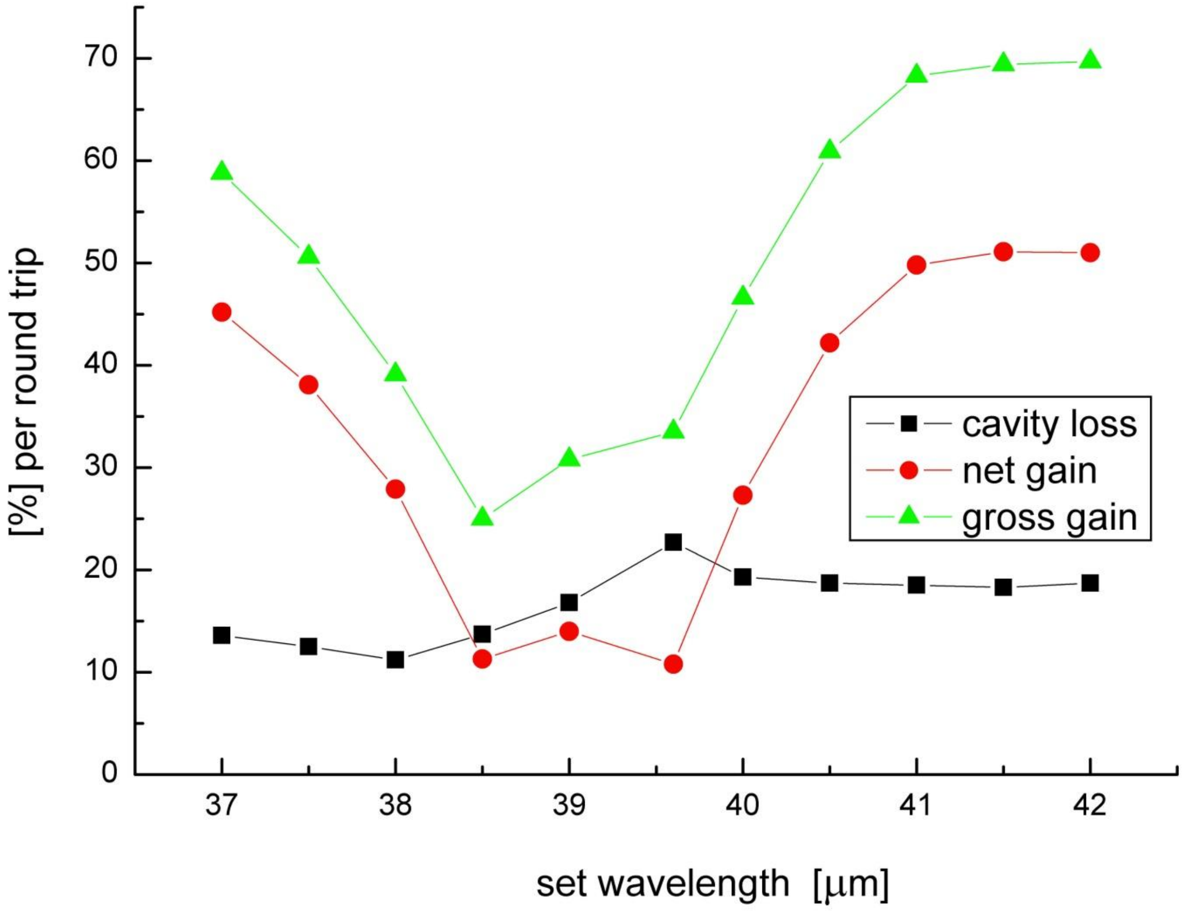
Frequency offset between n=1 and n=3



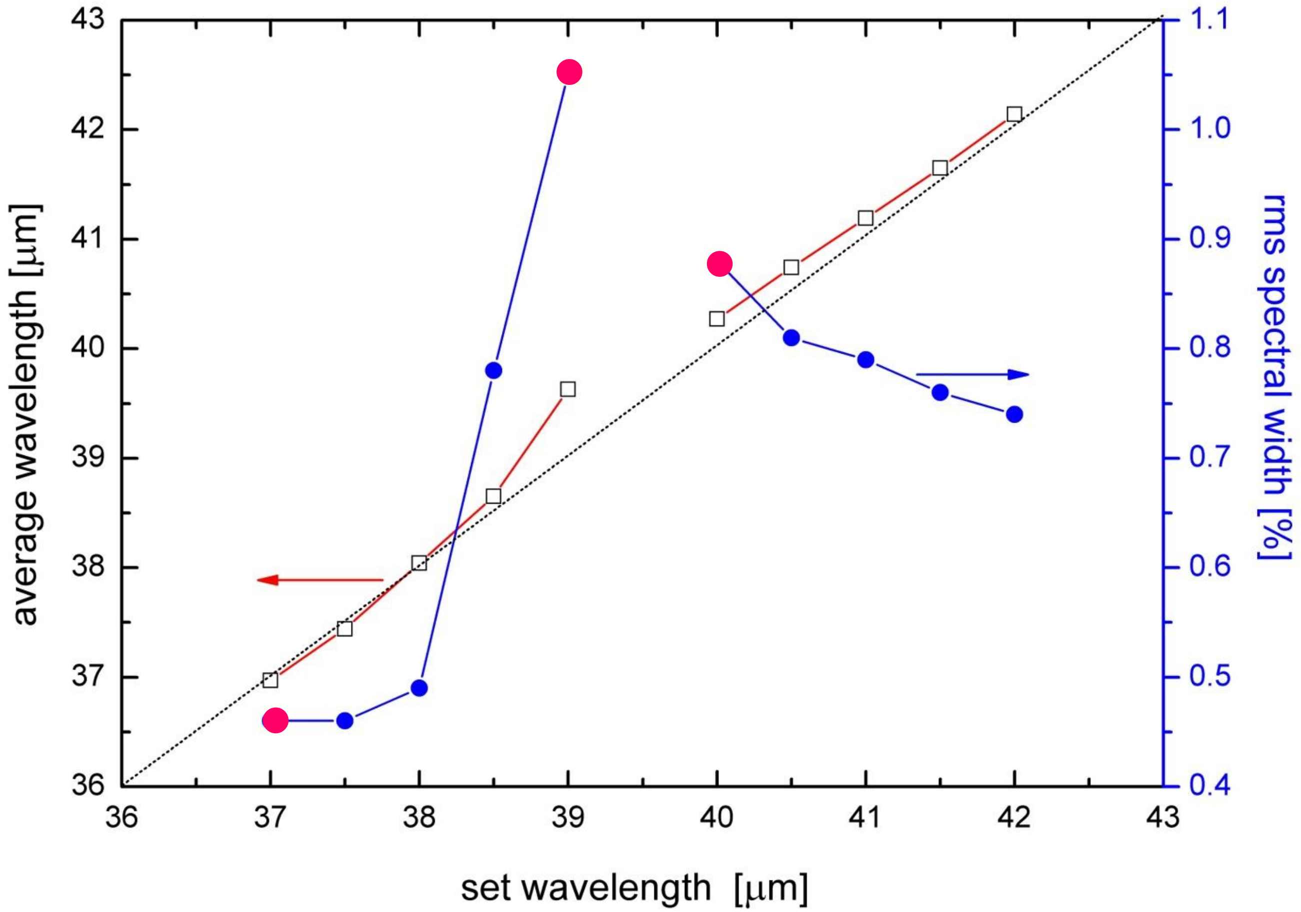
Typical tuning curve



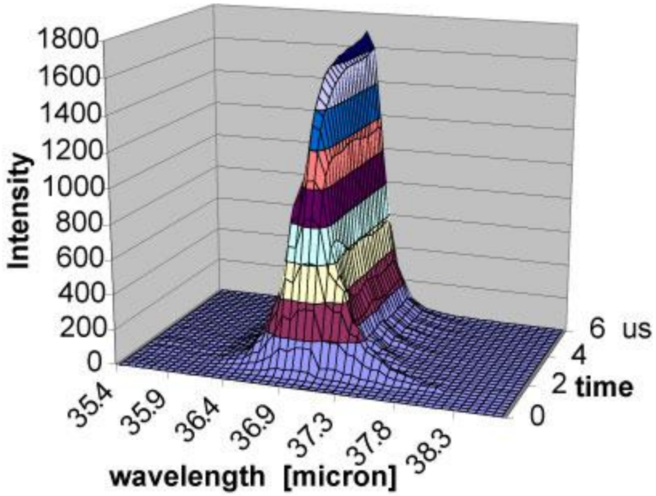
measured roundtrip gain and loss

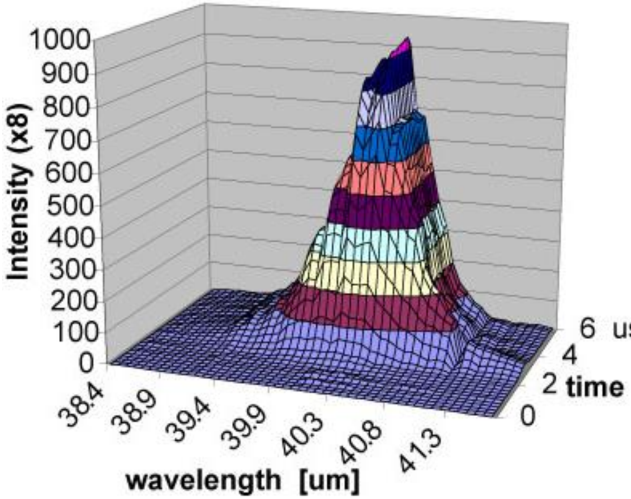


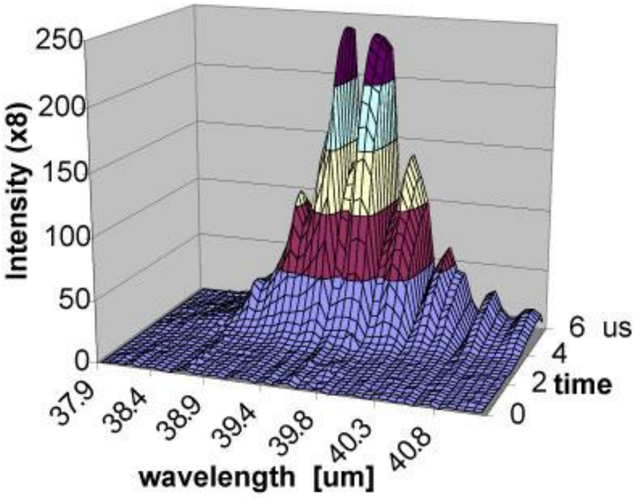
measured spectral characteristics



measured spectral characteristics cont.

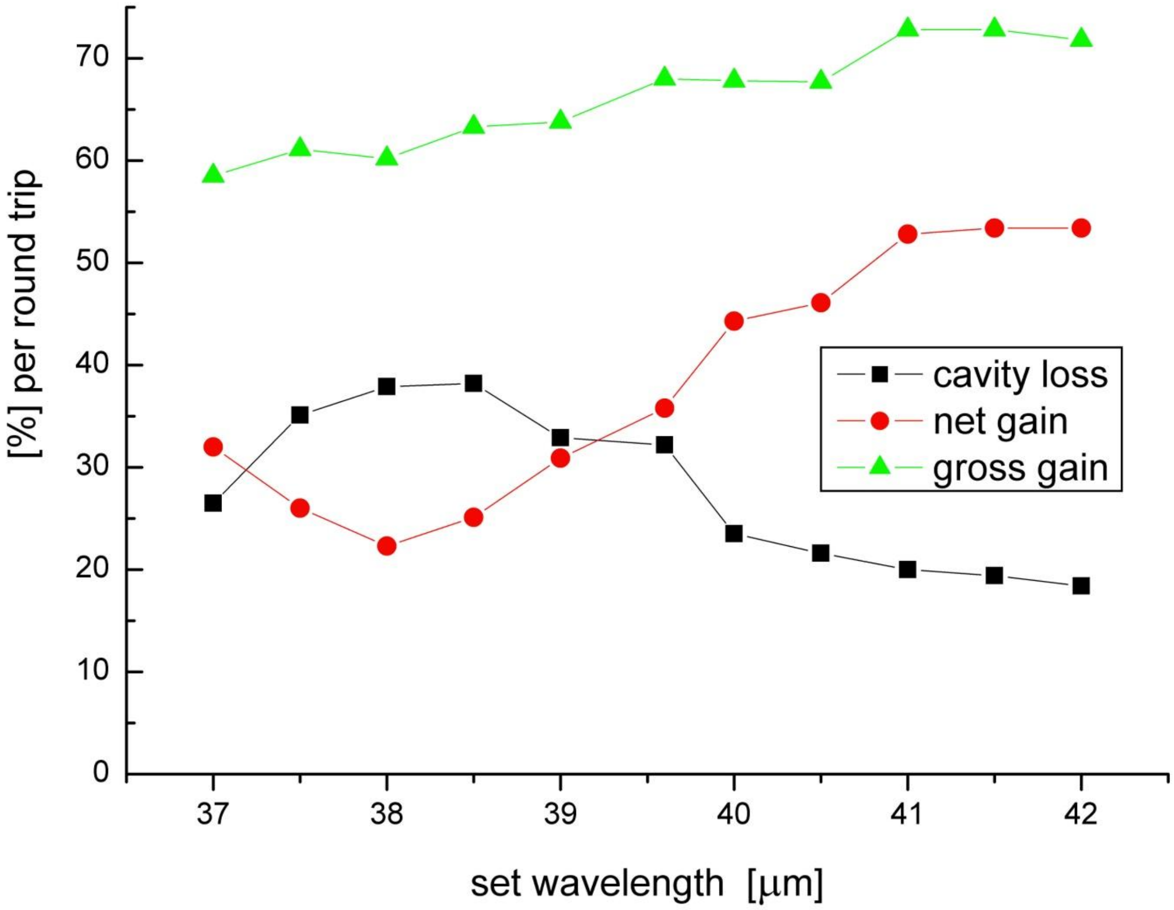




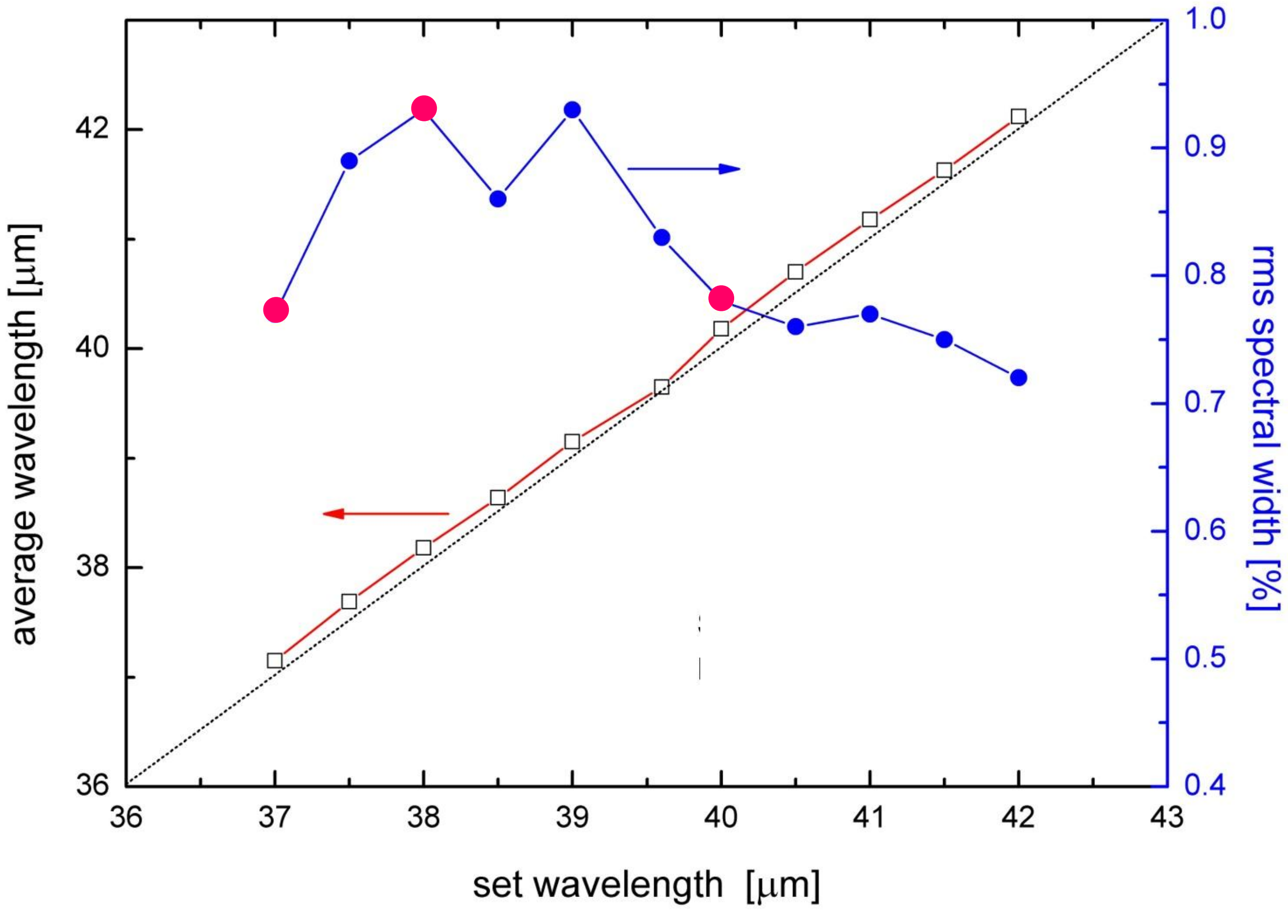


measured roundtrip gain and loss cont.

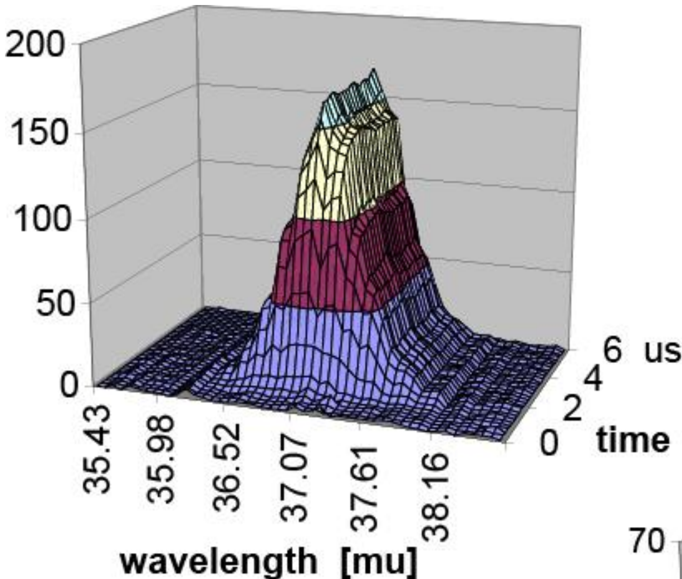
slit width = 15 mm

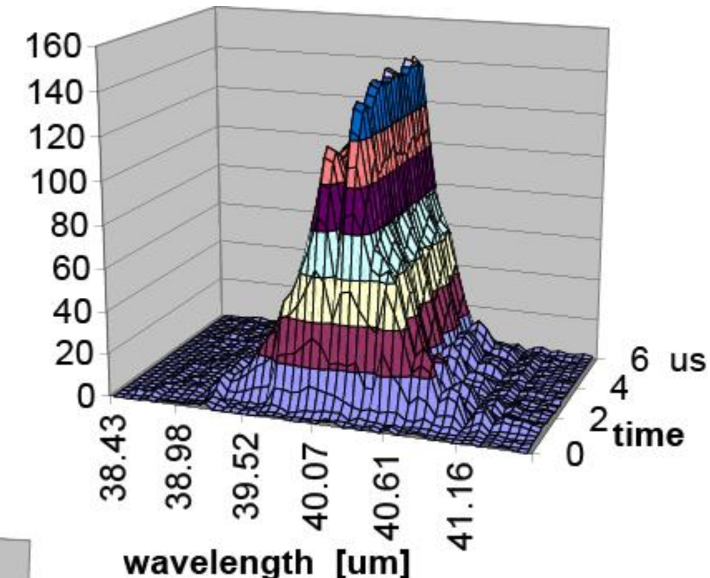


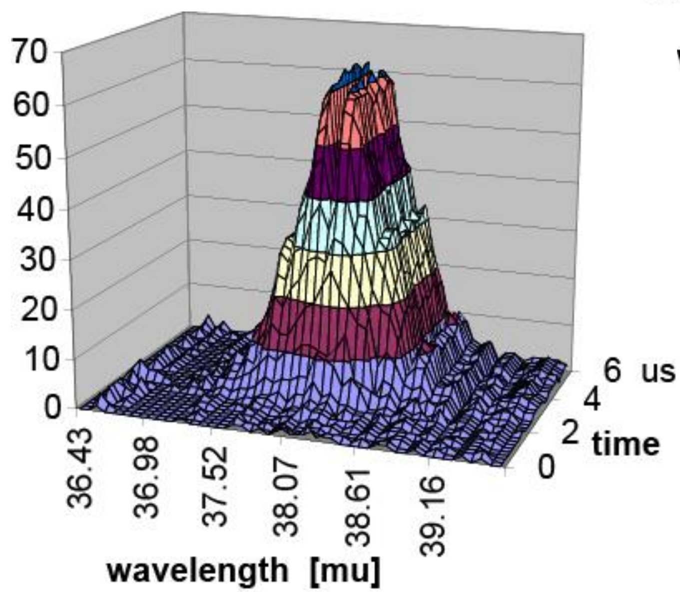
measured spectral characteristics cont.



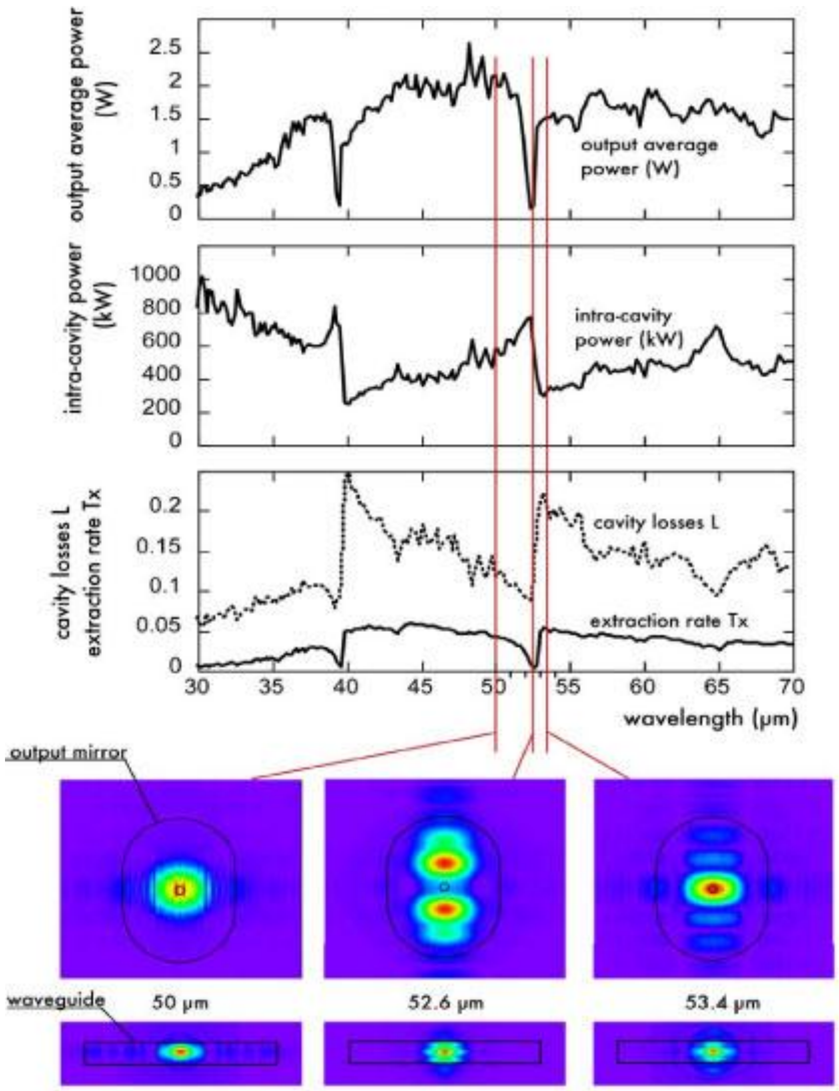
measured spectral characteristics cont.







Simulations by Prazeres et al.

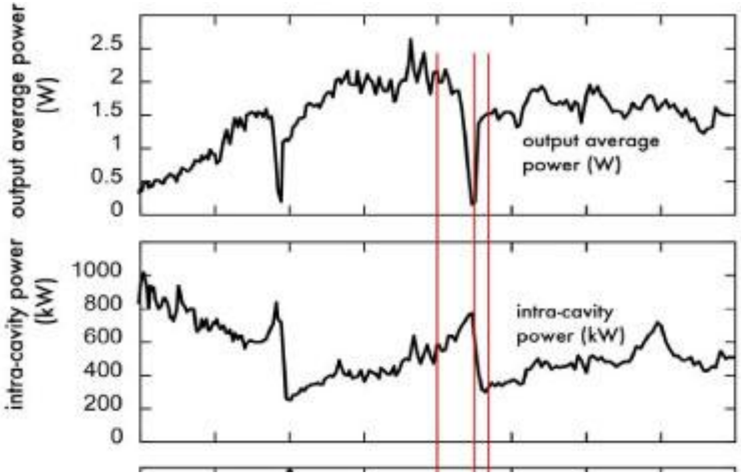


Prazeres et al.,

PRST Accel. Beams

12 (2009) 010701

Simulations by Prazeres et al.



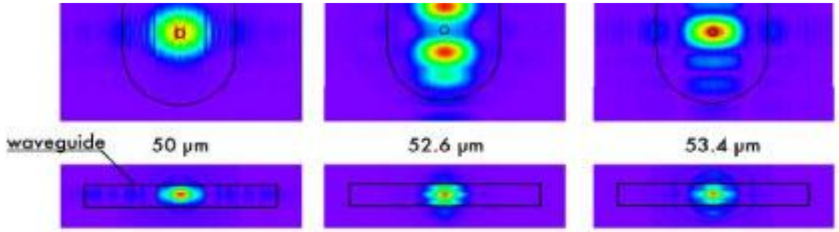
Prazeres et al.,

PRST Accel. Beams

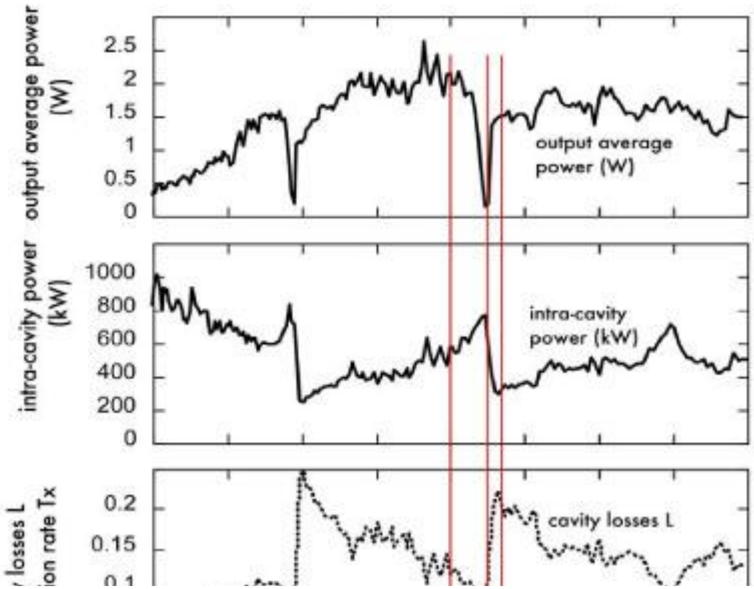
12 (2009) 010701

Limitations of the model used:

- single frequency
- no start-up
- gain evaluation only halfway the undulator



Simulations by Prazeres et al.



Prazeres et al.,
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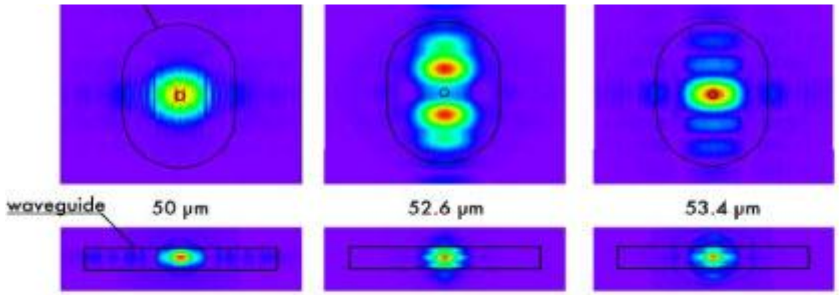
Conjecture:

spacing of gaps given by $\Delta\Phi^{w}{}_{1} - \Delta\Phi^{w}{}_{3} = 2\pi$



Our model

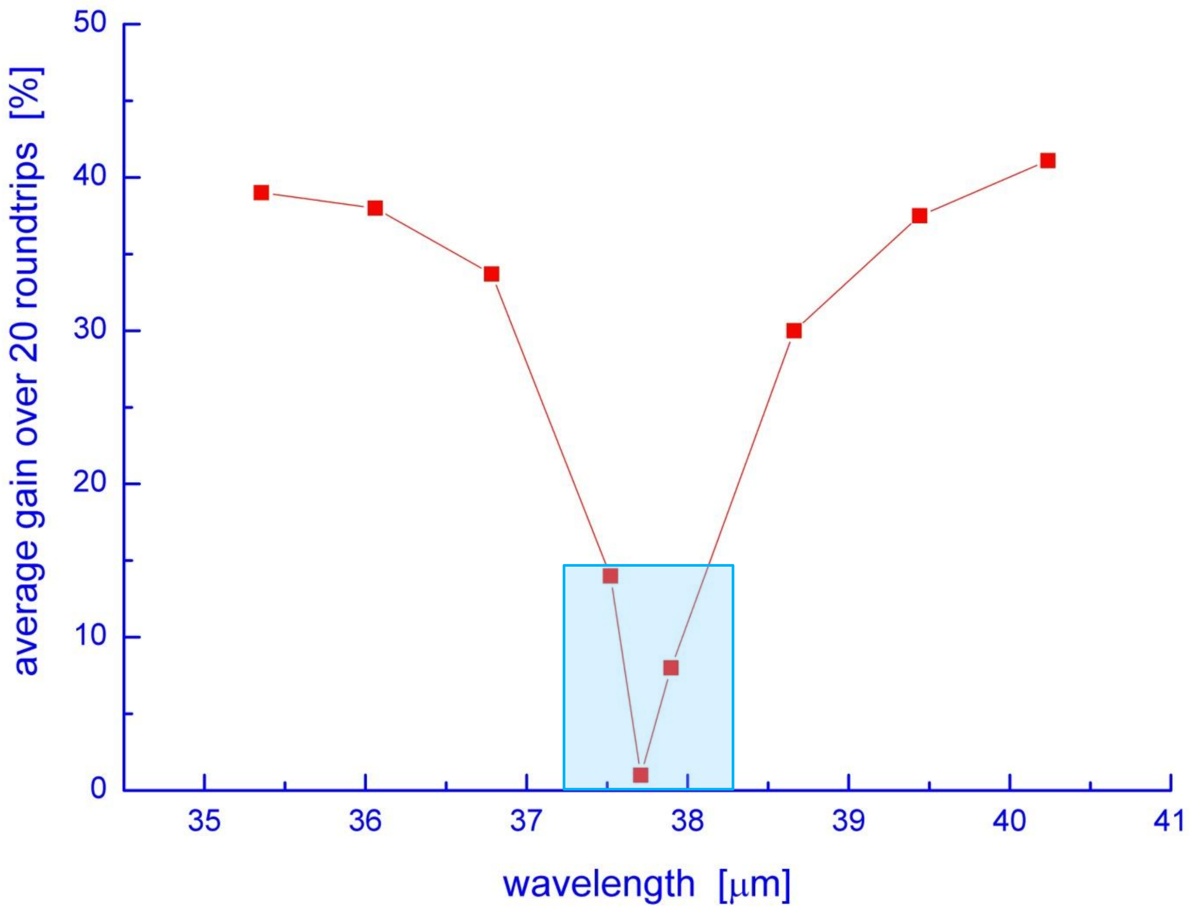
Modification of the model by Prazeres:

- single transverse coordinate (x), so no hole
- multi frequency, short pulse
- distributed, frequency dependent gain

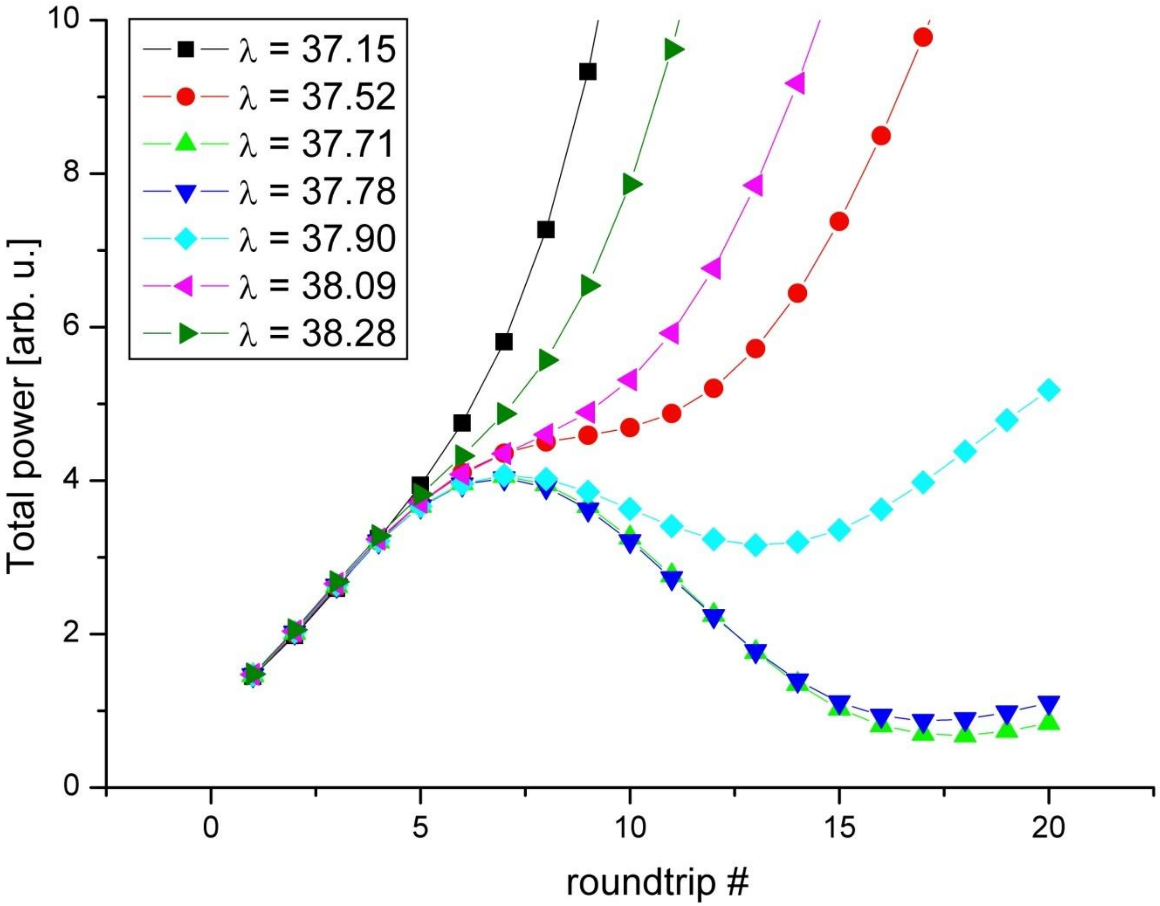
  (stepwise integration of small-signal, low-gain FEL equation

  along the undulator and across the e-beam profile)

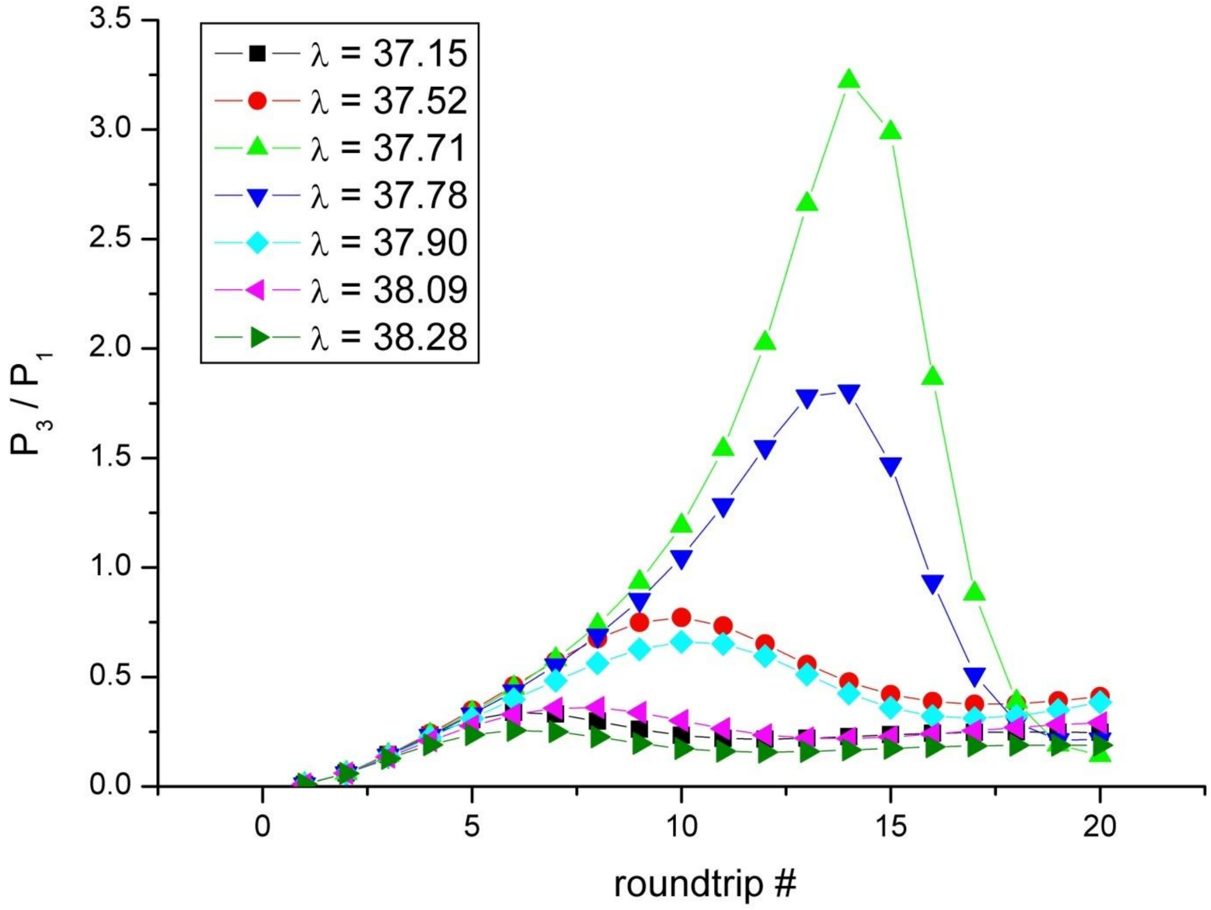
Our simulation results



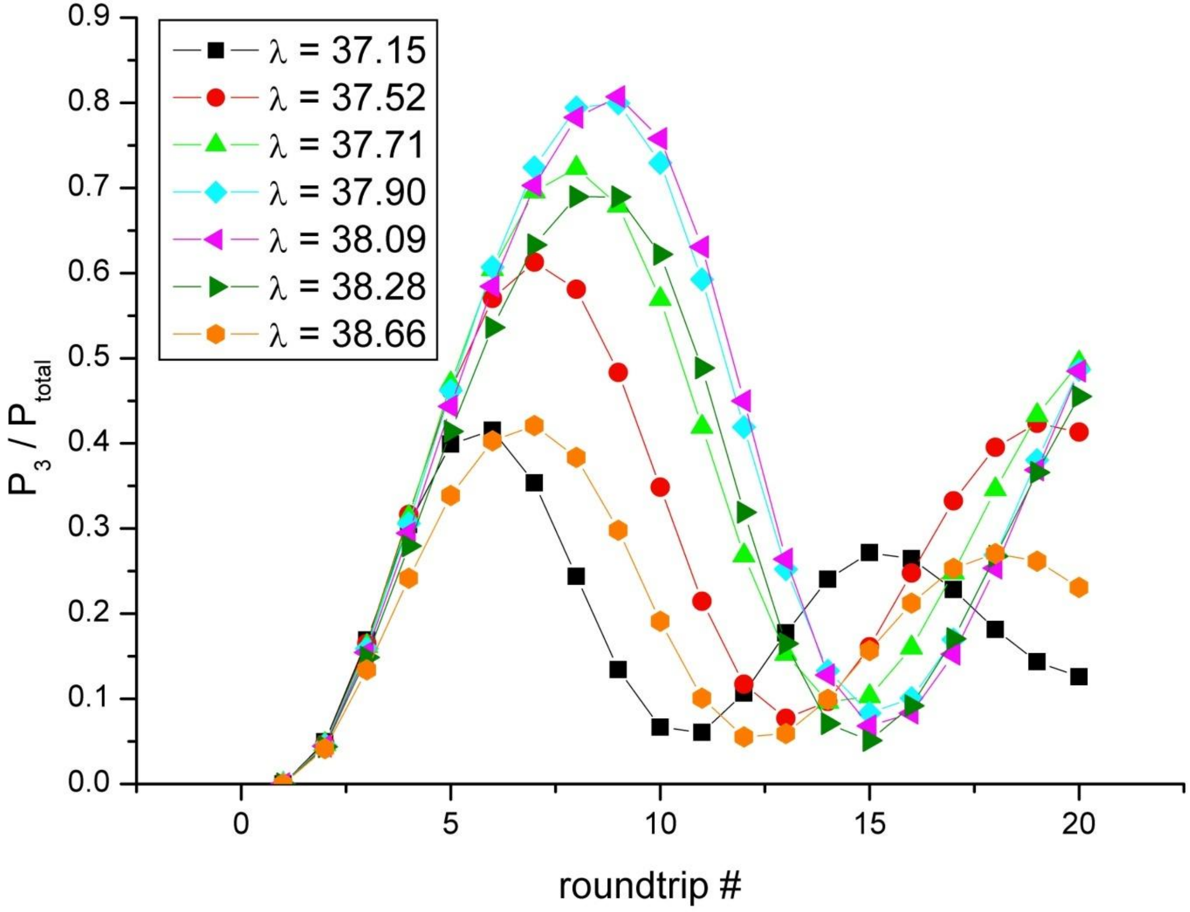
Our simulation results



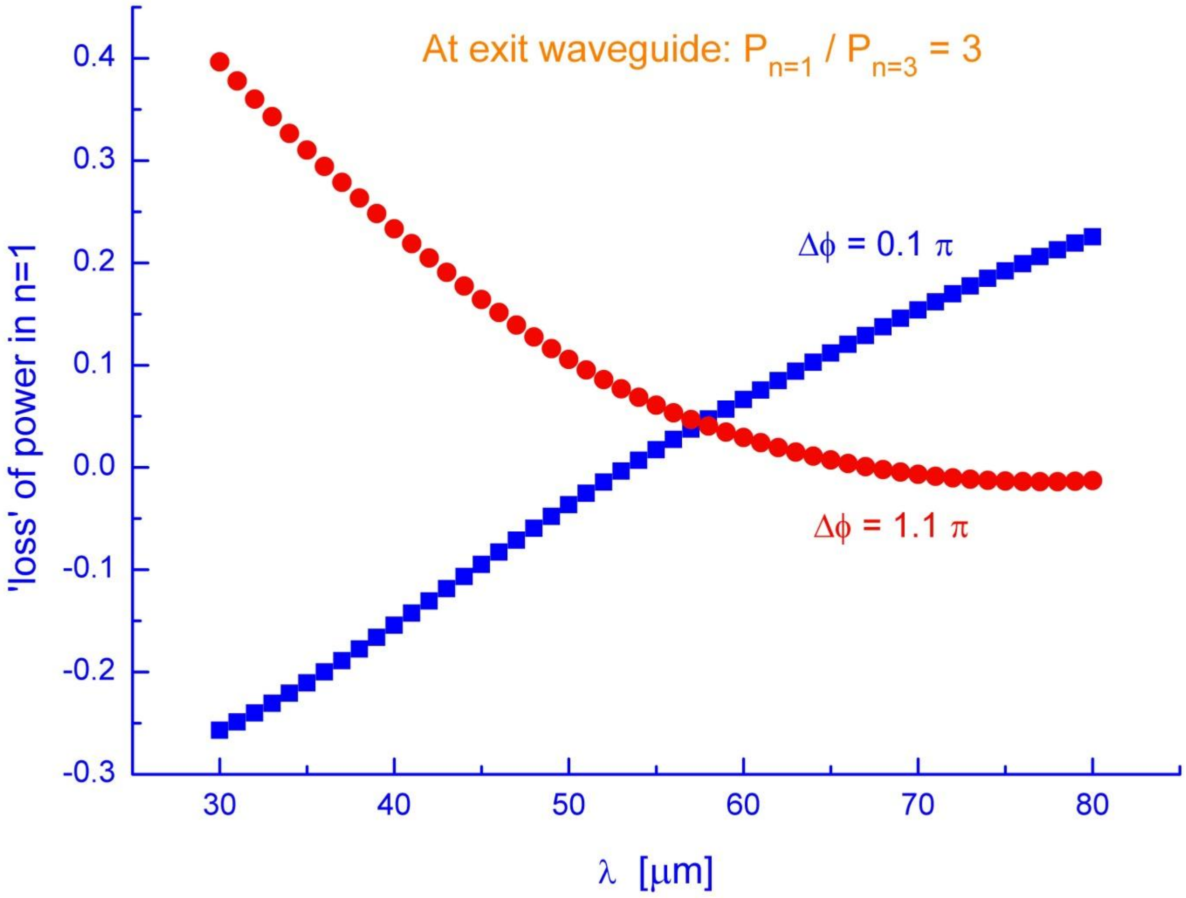
Our simulation results cont.



Our simulation results cont.



conversion in free space with $P_{n=3}$ present



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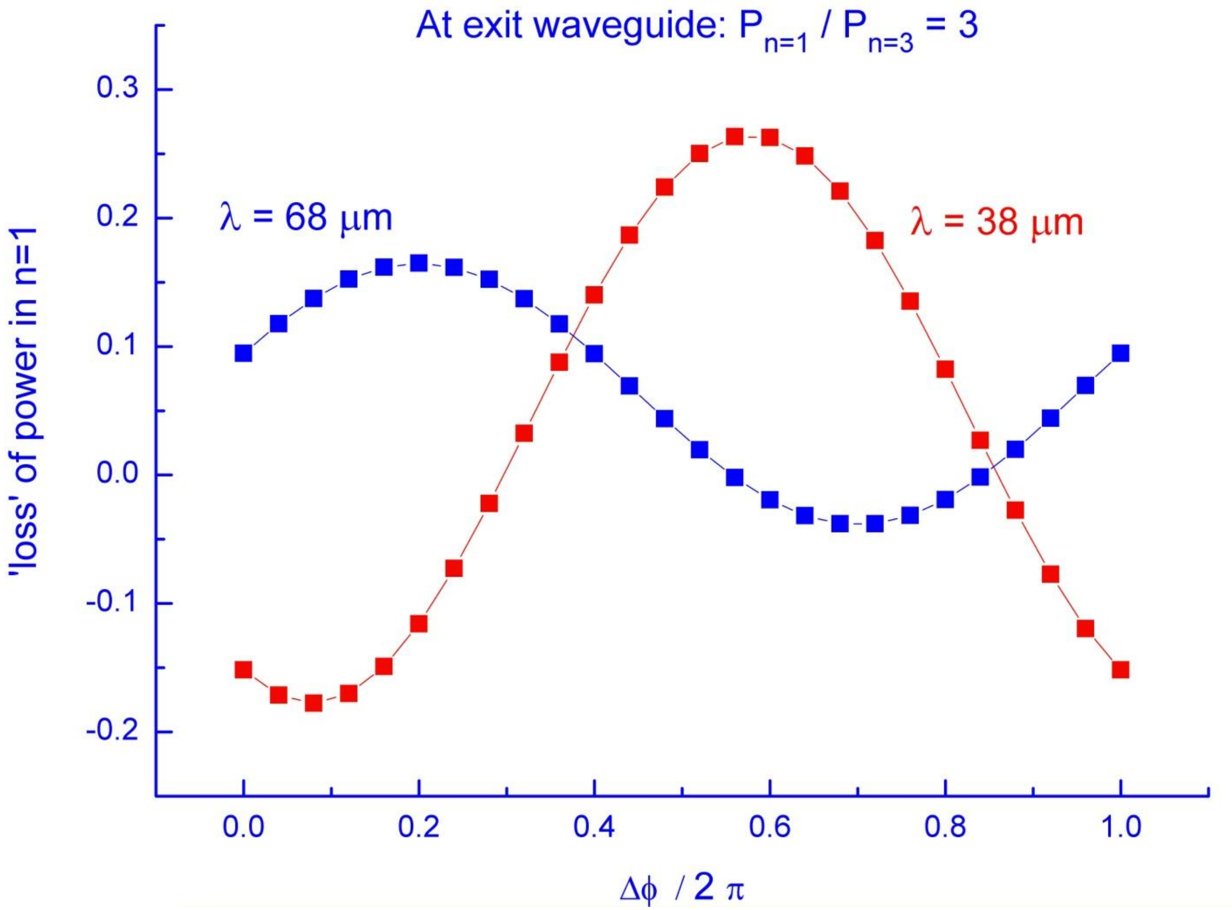
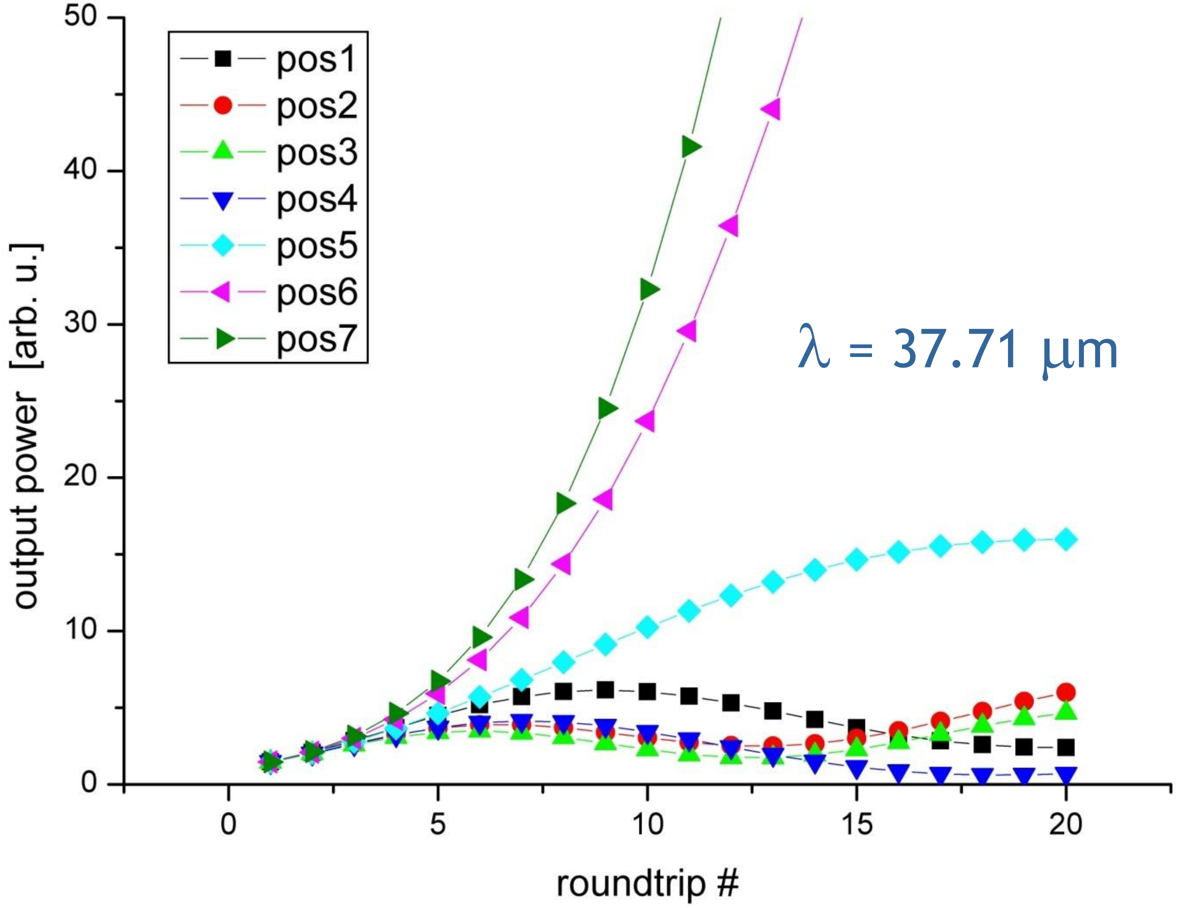


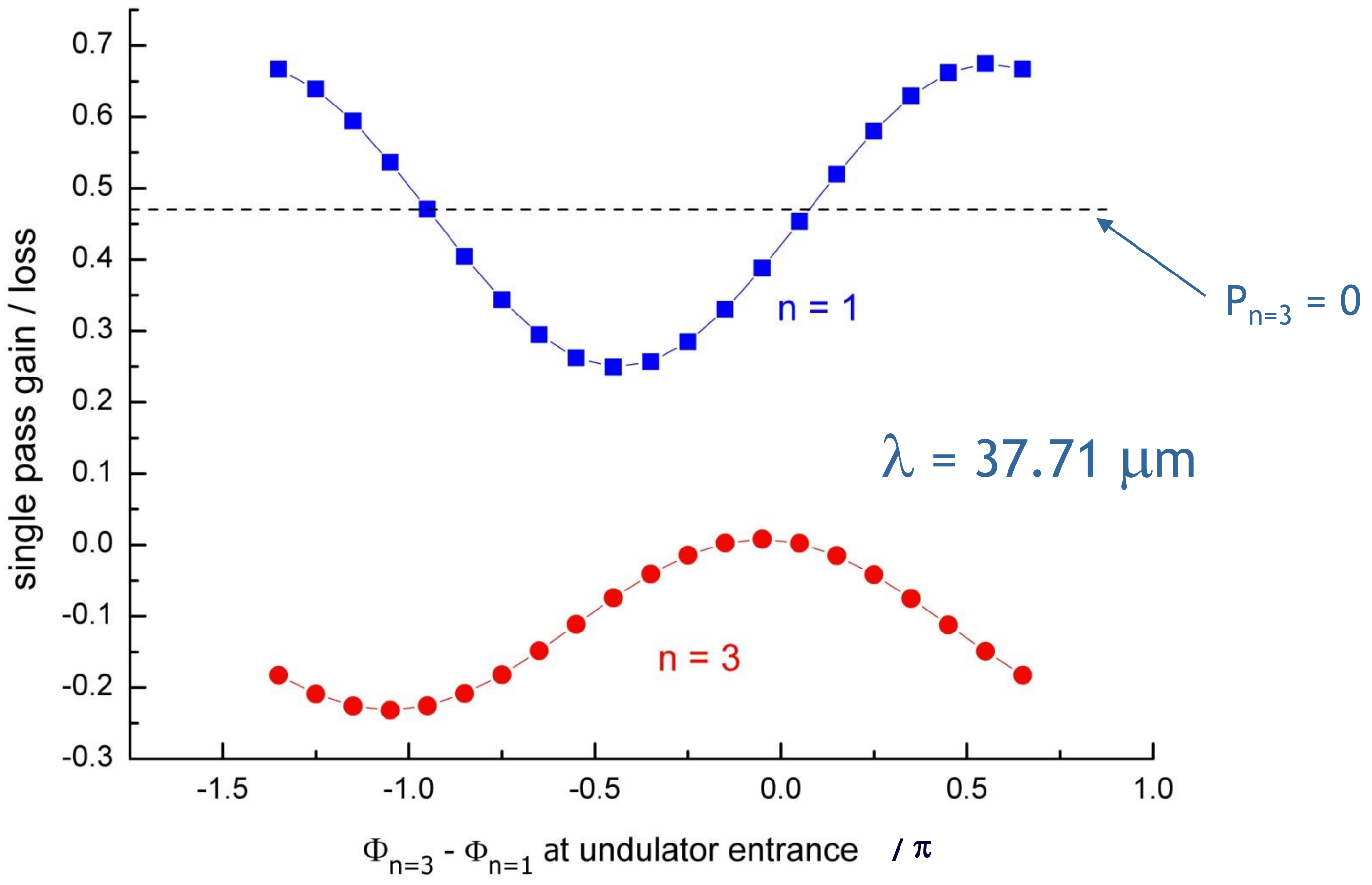
Gain vs. undulator position



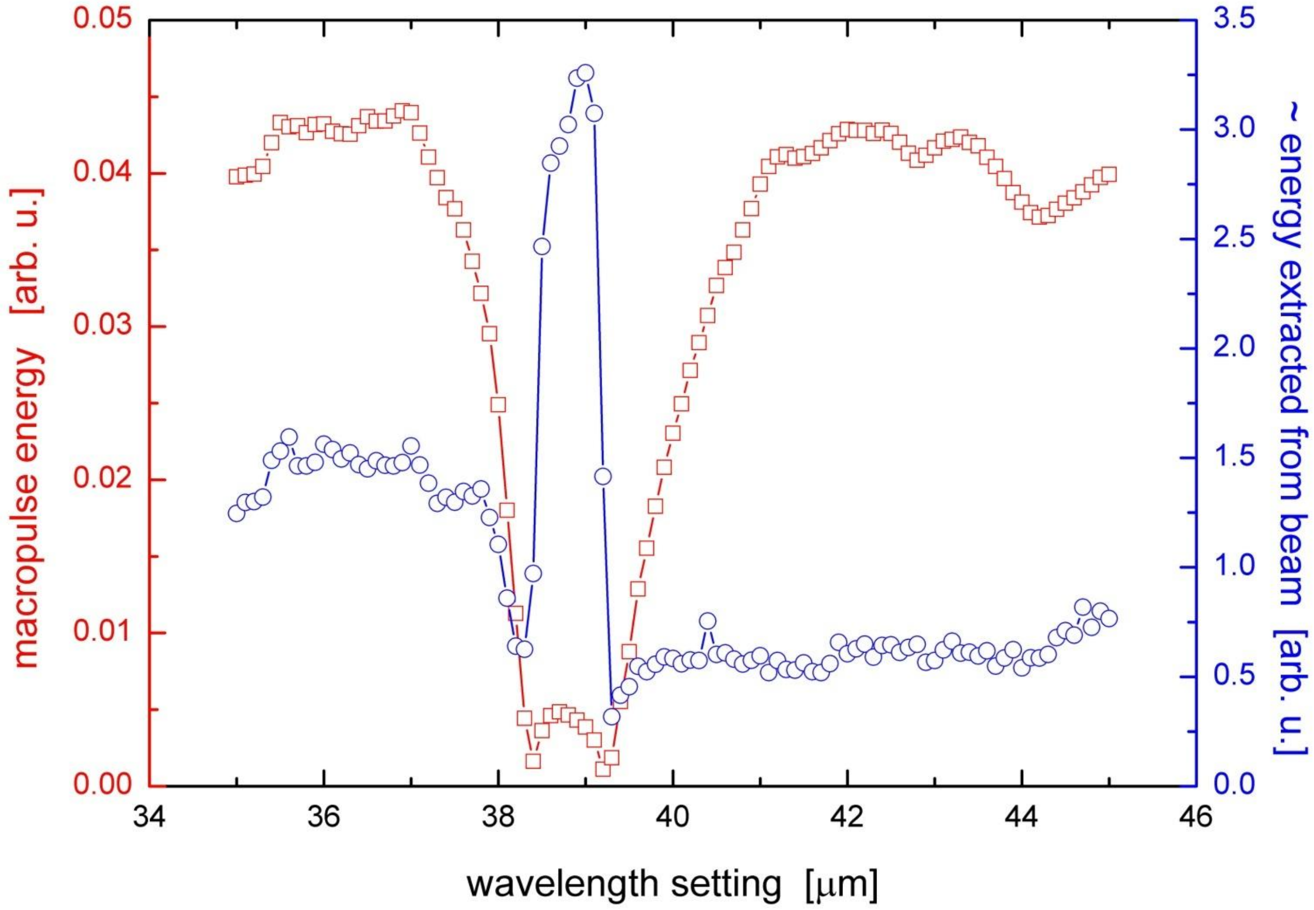
λ = 37.71 μm

Single pass undulator gain vs. relative phase

Input: $P_{n=3} = P_{n=1}$

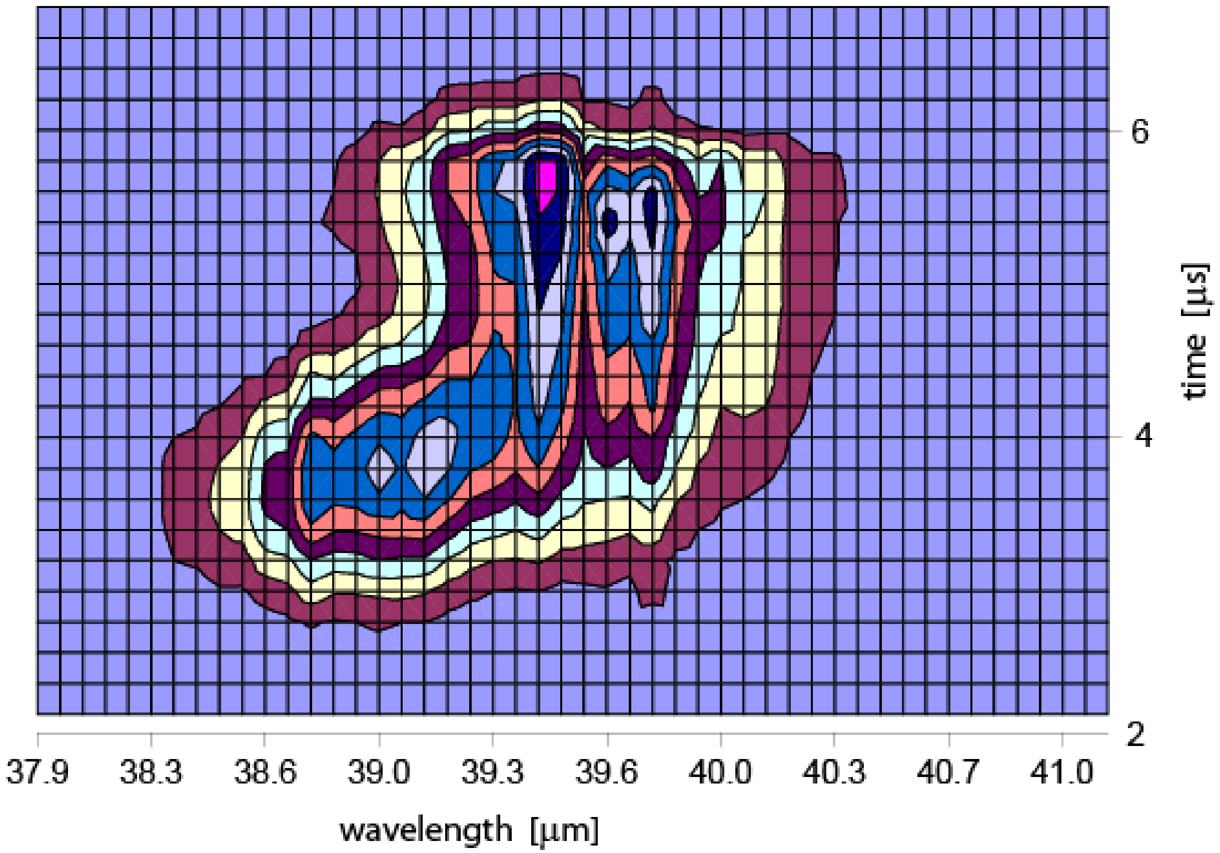


Example of low outcoupling



Example of low outcoupling

wavelength setting: 39 μm



Conclusions

Start-up problem and power gaps are caused by

1. the resonant mode conversion from the $n = 1$ mode to higher-order modes between waveguide exit and entrance when the relative, roundtrip phase shift is a multiple of 2π

2. the dependence of the gain of the $n = 1$ mode on the relative phases of the higher-order transverse modes along the undulator