The 4GLS VUV-FEL:
a Regenerative Amplifier FEL (RAFEL) design

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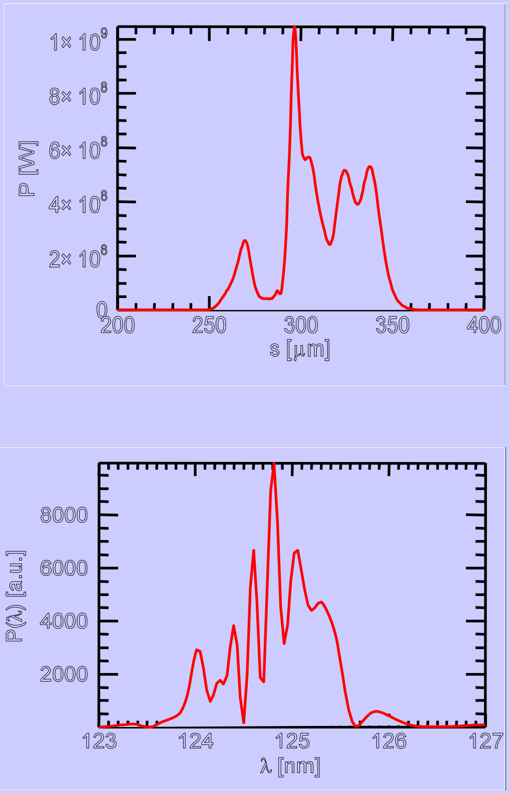
RAFEL: Regenerative Amplifier FEL

- The RAFEL is a high-gain self-seeding FEL
- Optics are required but:
  - gain is very high (~10,000%) so reflectivity can be very low
  - radiation is not stored in cavity over many passes so tolerances on alignment and thermal loading are reduced
  - cavity just provides a seed pulse for next pass
- Electron beam shot noise is averaged out over a few passes giving smooth pulse: significantly enhanced over SASE

SASE



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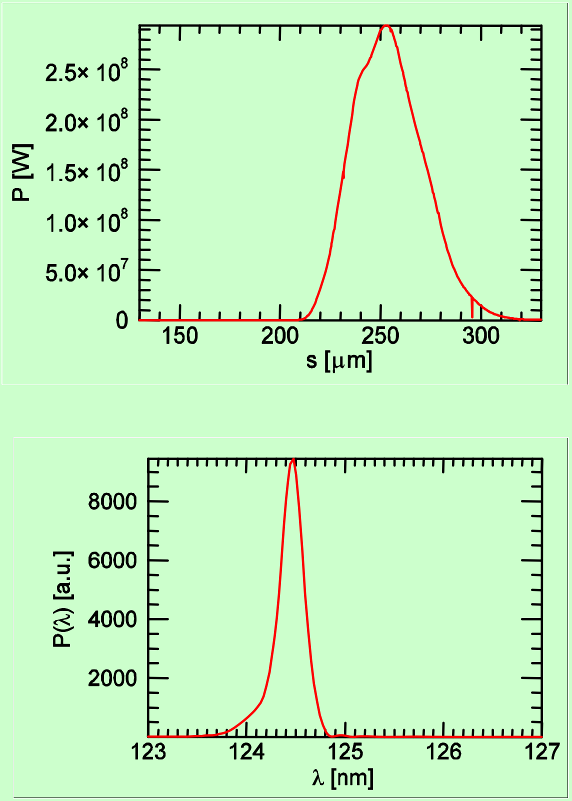
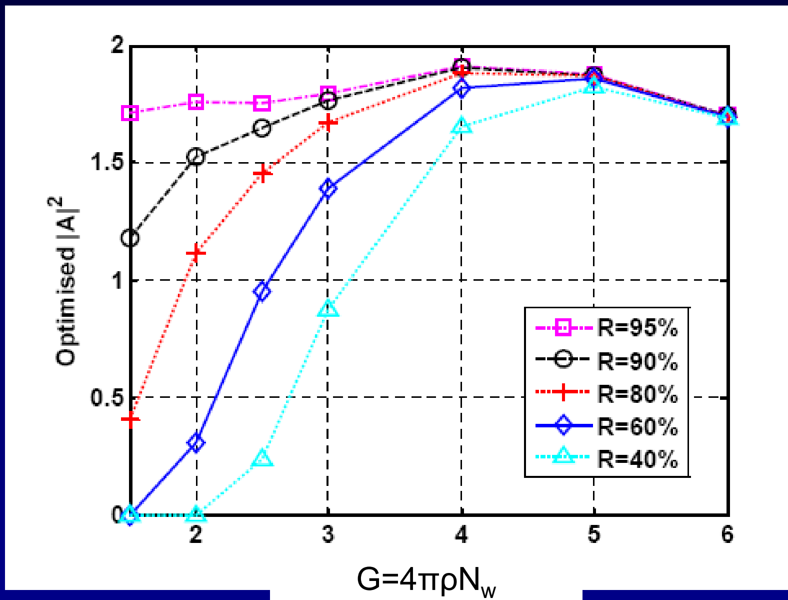
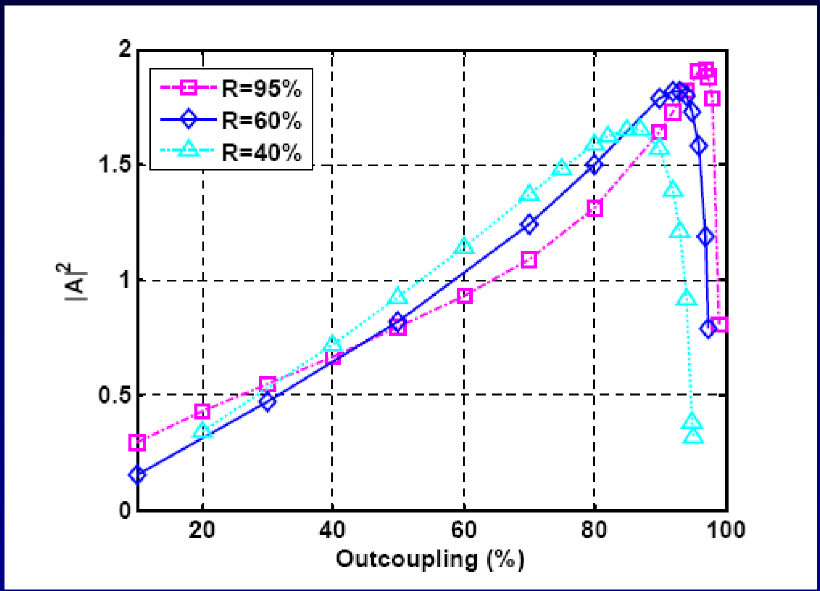


Parameters for RAFEL regime

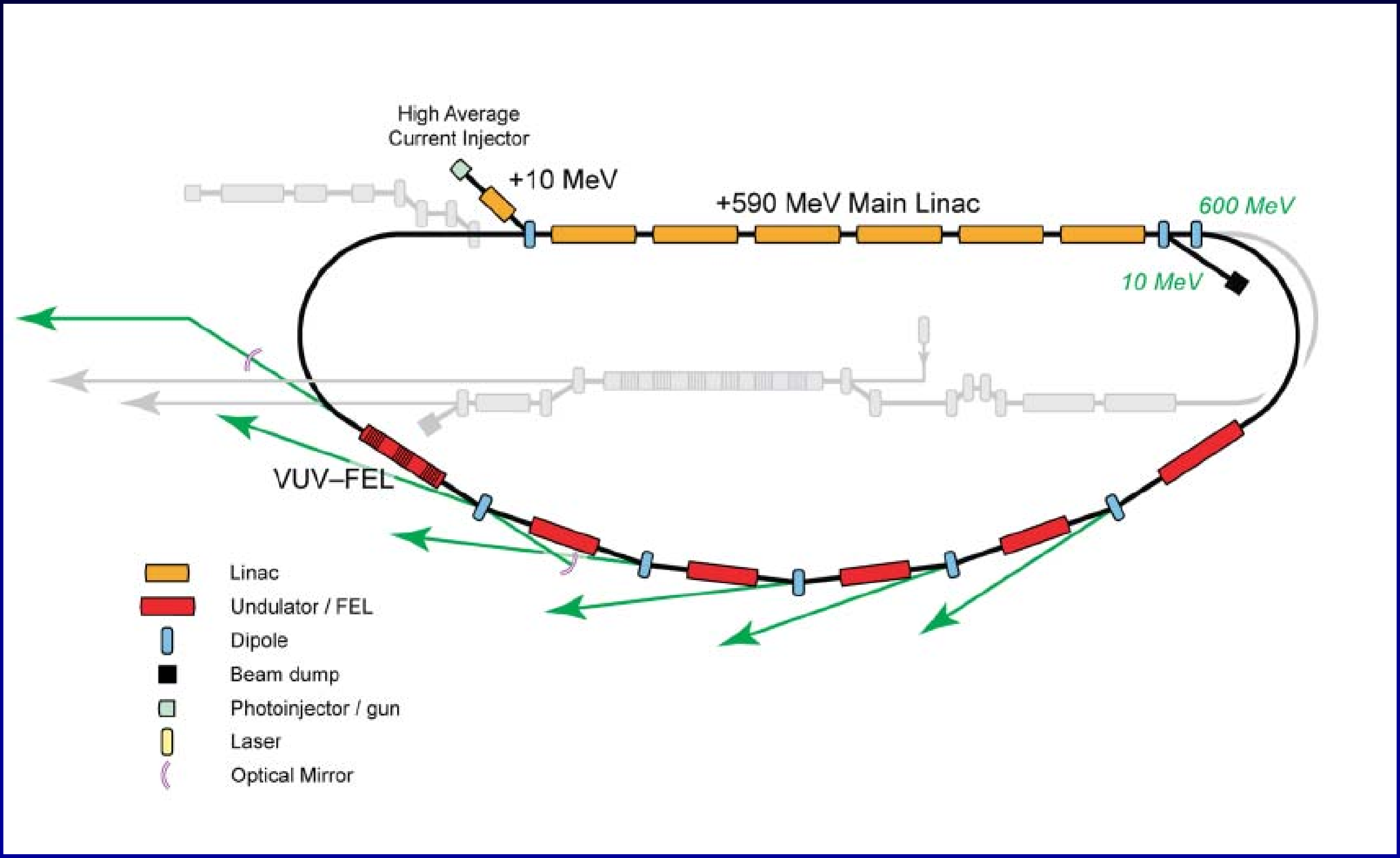




- For $G > 4$ output intensity becomes relatively insensitive to reflectivity
- Assuming $G = 4$, higher reflectivity gives higher max output power, but more sensitivity to outcoupling fraction

Choose **G = 4** (low reflectivity OK), **R = 60%** (feasible with coated Al), **outcoupling = 75%** (stability)

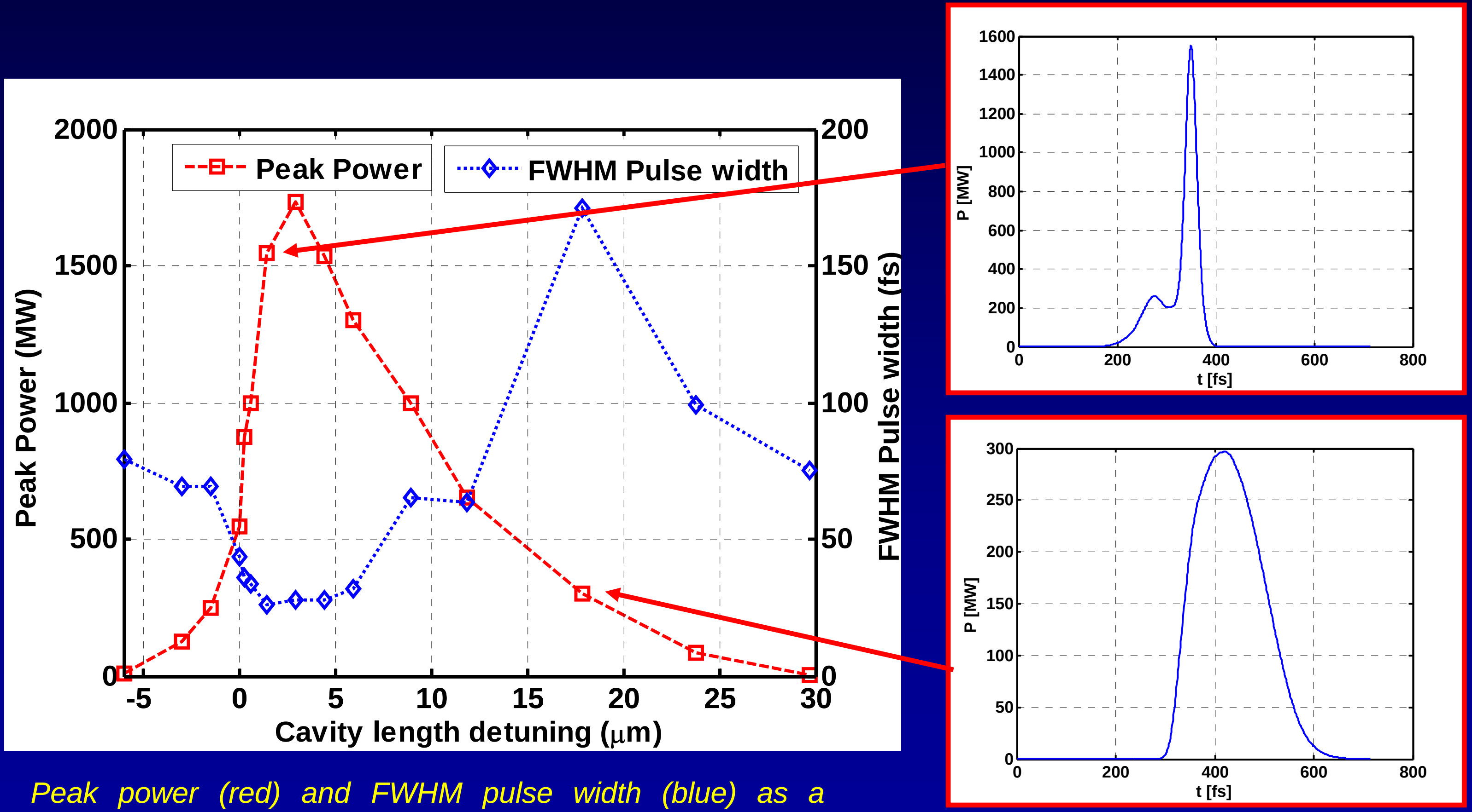
The VUV-FEL in 4GLS



Beam and Undulator parameters

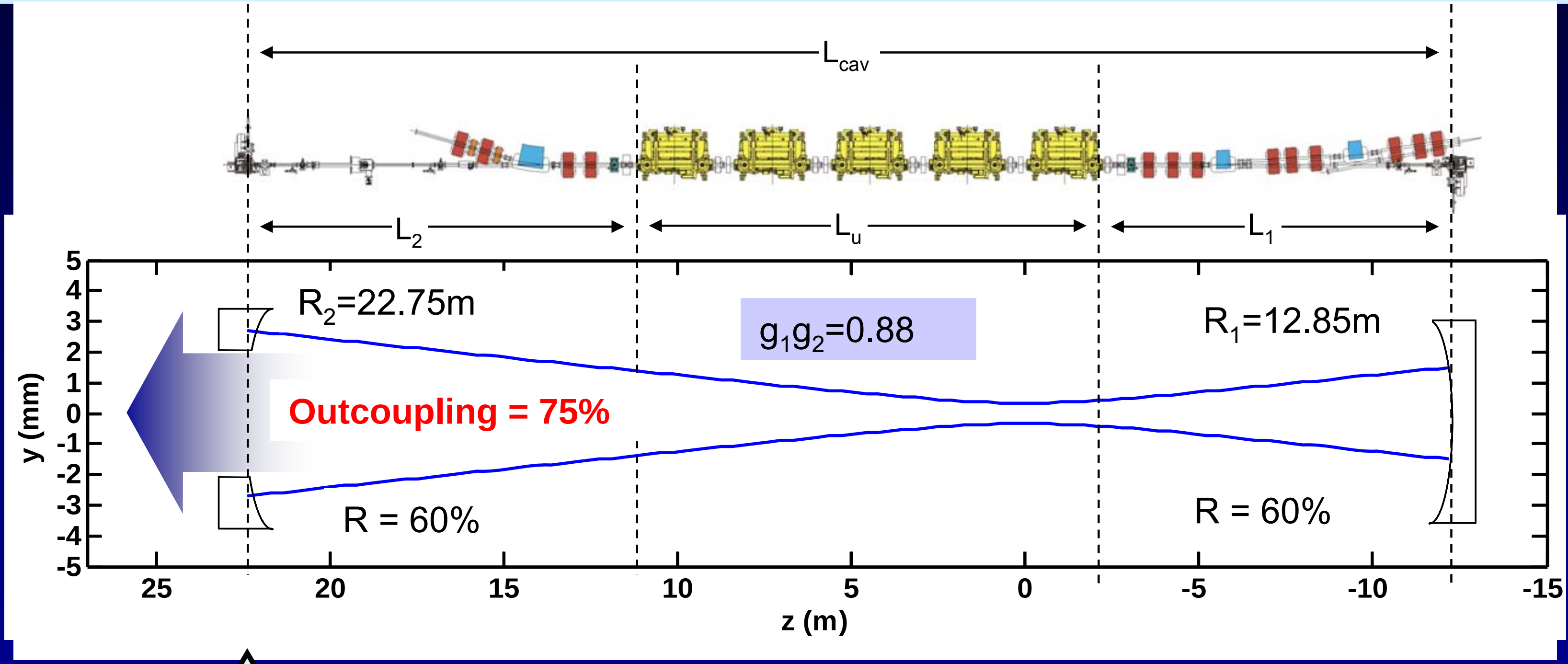
ELECTRON BEAM PARAMETERS	
Energy	600 MeV
Bunch Charge	77 pC
RMS bunch length	100 fs
Peak current	300 A
Average current	n × 333 μA
Normalised emittance	2 mm mrad
RMS energy spread	0.1%
UNDULATOR PARAMETERS	
Undulator Type	APPLE-II
No of Modules	5
Module length	2.2 m
Period	60 mm
Focussing	FODO
Minimum gap	10 mm

1D time-dependent simulations



Peak power (red) and FWHM pulse width (blue) as a function of VUV-FEL cavity detuning. The parameters are for 10eV photon output.

Cavity parameters in CDR



Hole size chosen to be slightly smaller than spontaneous emission spot size on first pass

Mirror ROC then chosen, assuming cold cavity mode, to give:

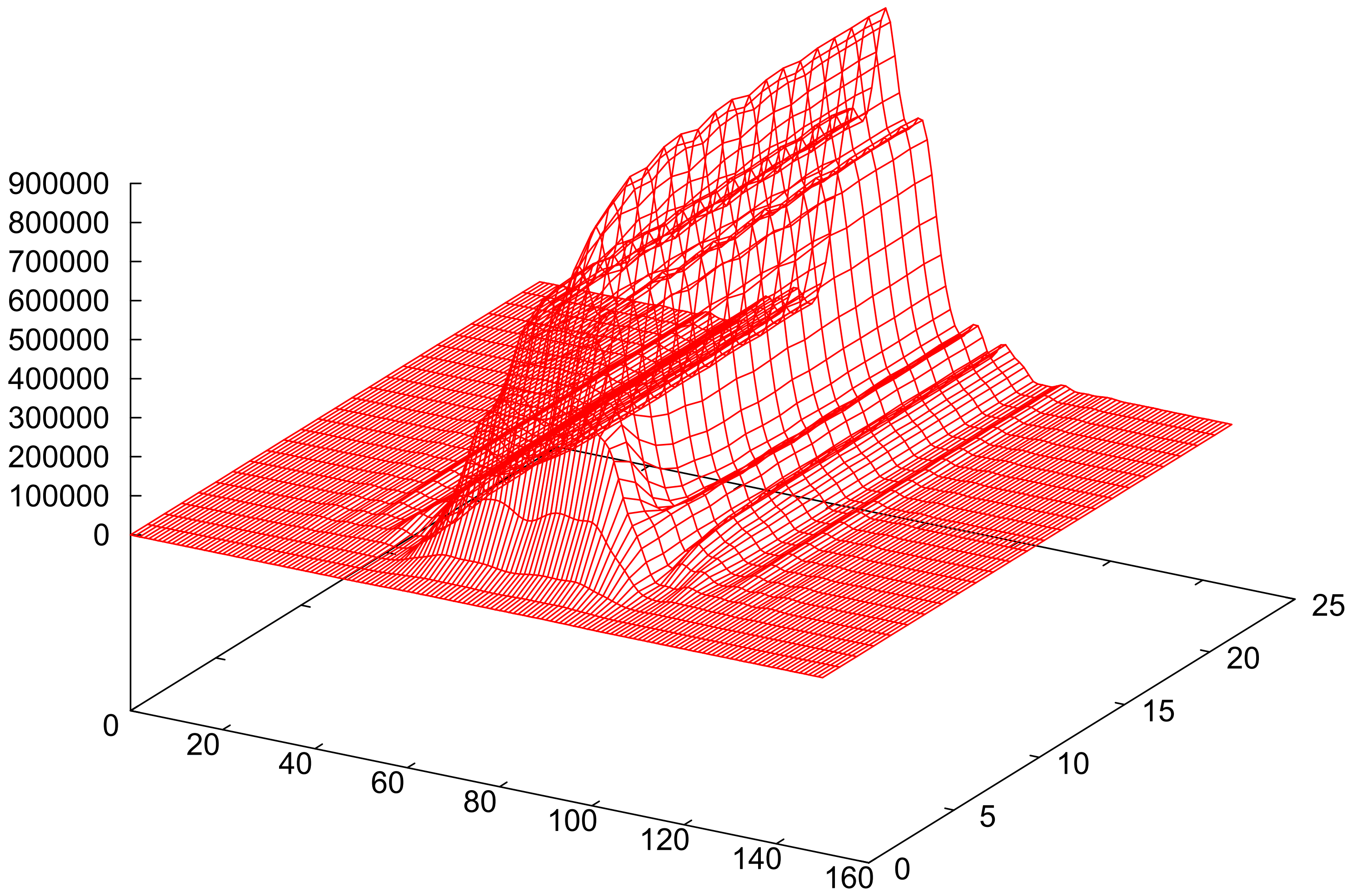
- waist near entrance to undulator (to optimise seeding)
- spot size on mirror appropriate for 75% outcoupling with chosen hole size

i.e. match opening angle of spontaneous emission to divergence angle of fundamental cavity mode

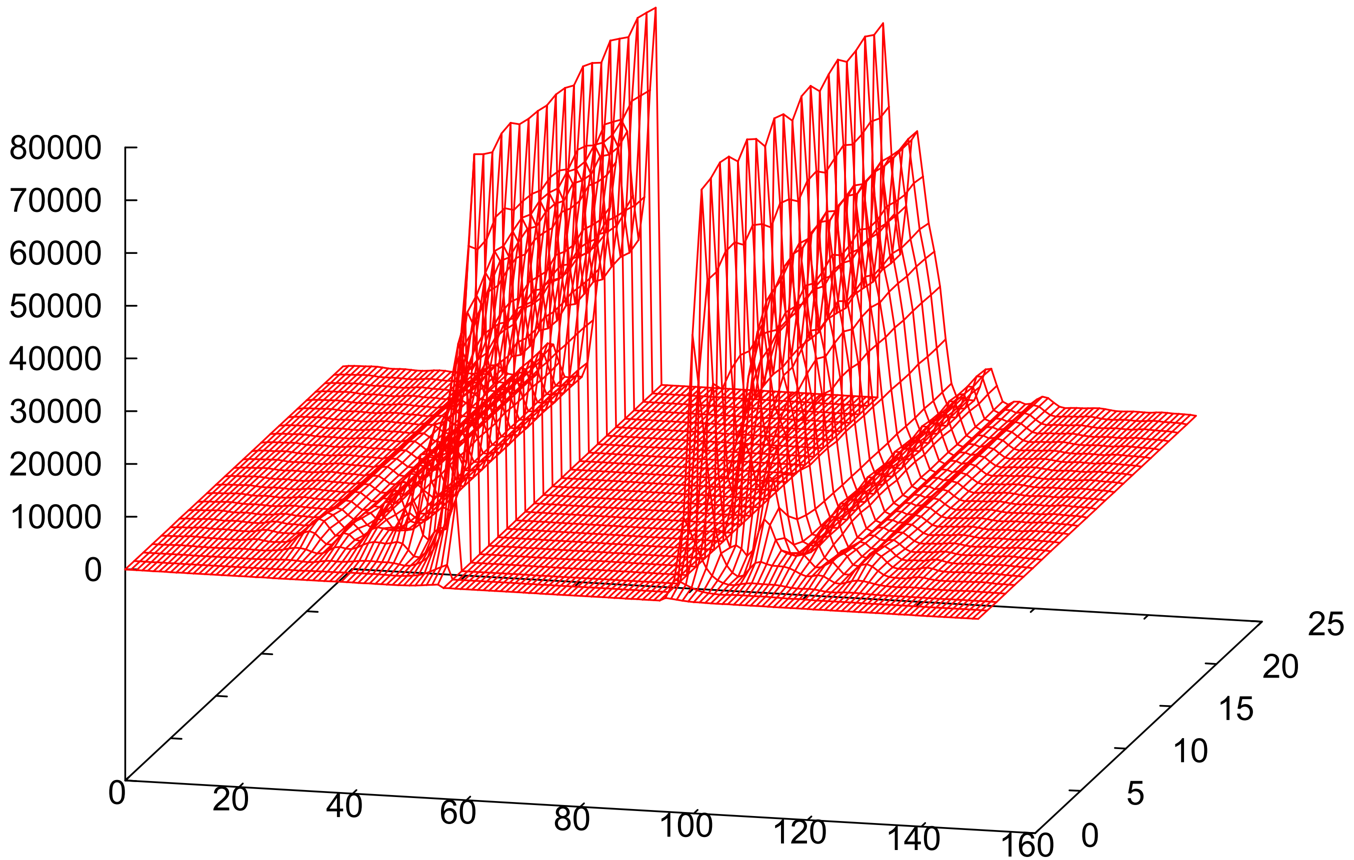
Genesis 1.3 + 3D optics simulations

- **3D optical propagation code**
- developed by University of Twente
  (P J M van Der Slot, J Karssenberg, I Volokhine)
- Propagates Genesis 1.3 output field through
  - free space
  - mirrors + tilted mirrors
  - holes
  - lenses
- Propagation with two related methods
  - Spectral Method
  - Fresnel integrals
- Currently steady state
- Soon time-dependent, including cavity length detuning + parallelisation.
- *See papers at FEL 2006*

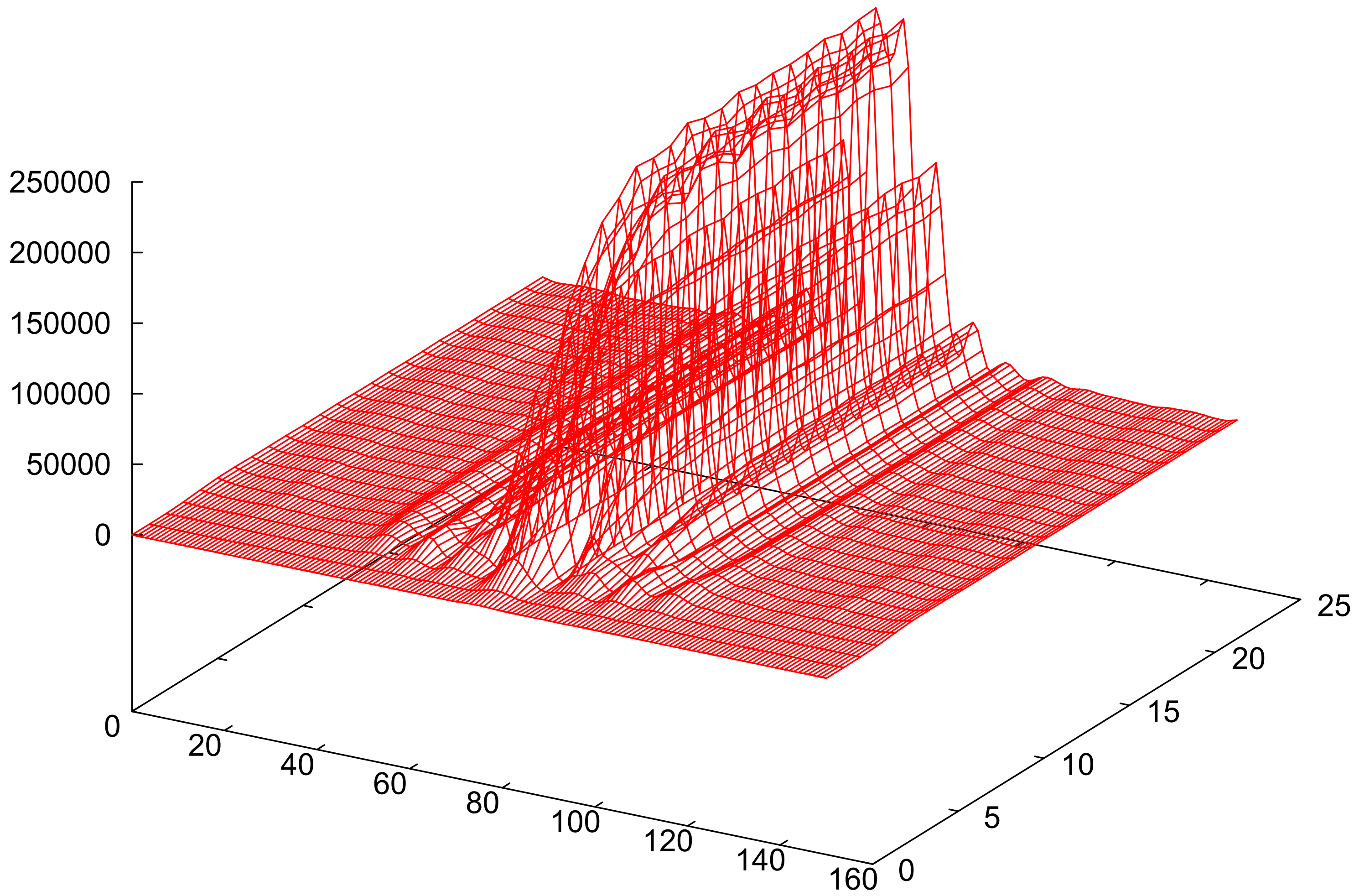
4mm hole: incident on DS mirror



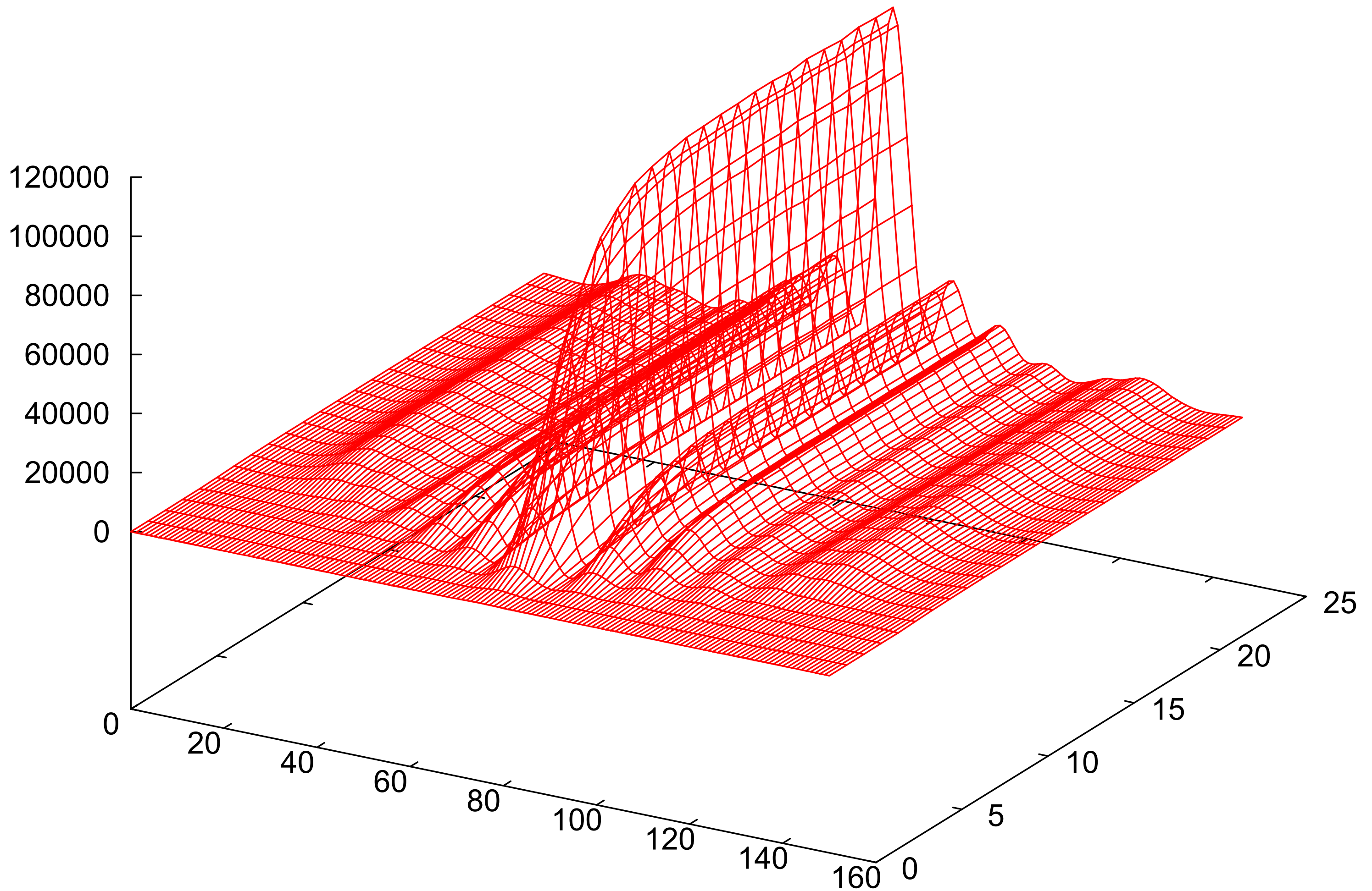
4mm hole: reflected from DS mirror



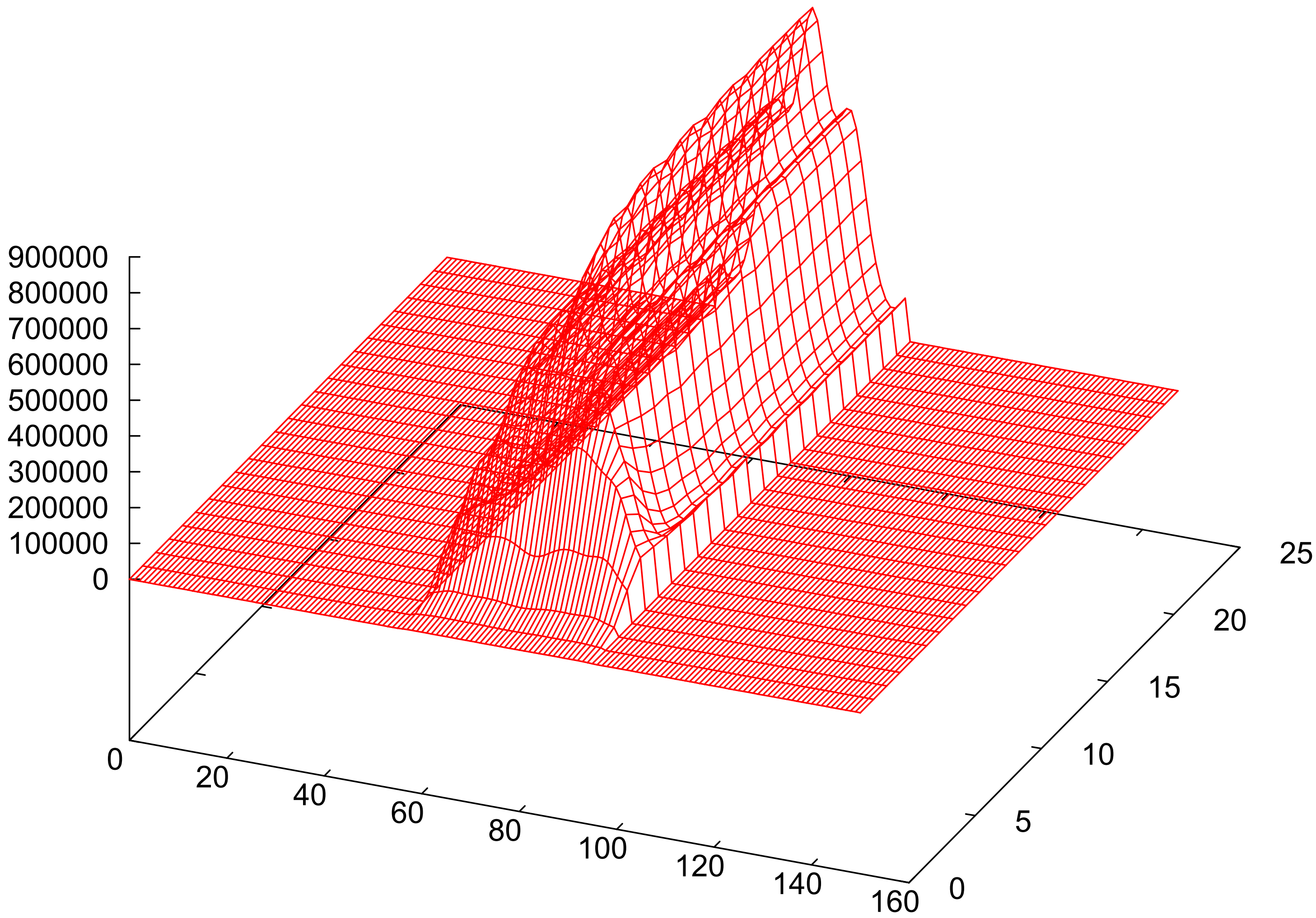
4mm hole: incident on upstream mirror



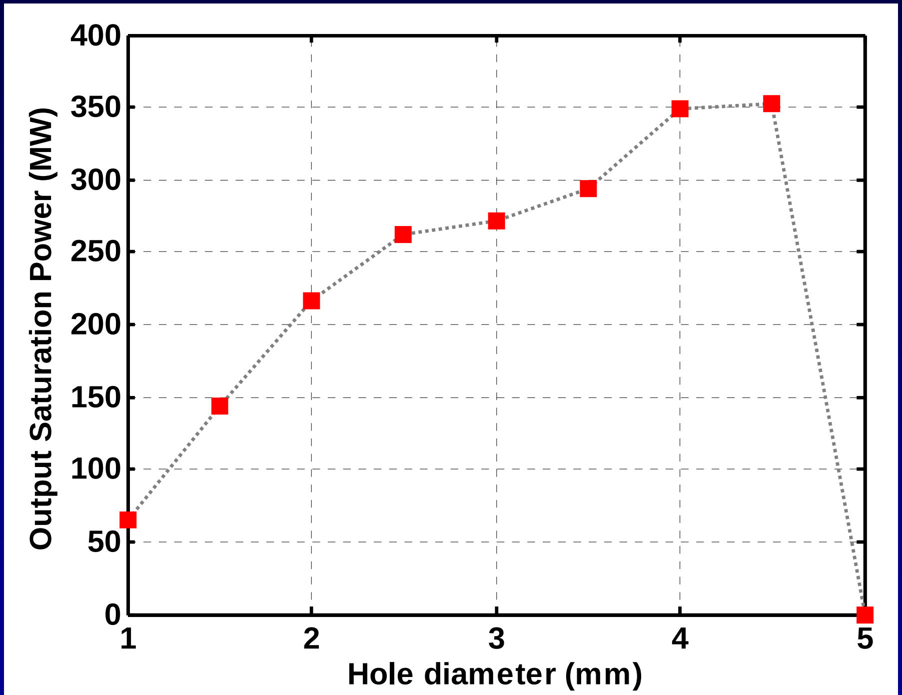
4mm hole: back into undulator

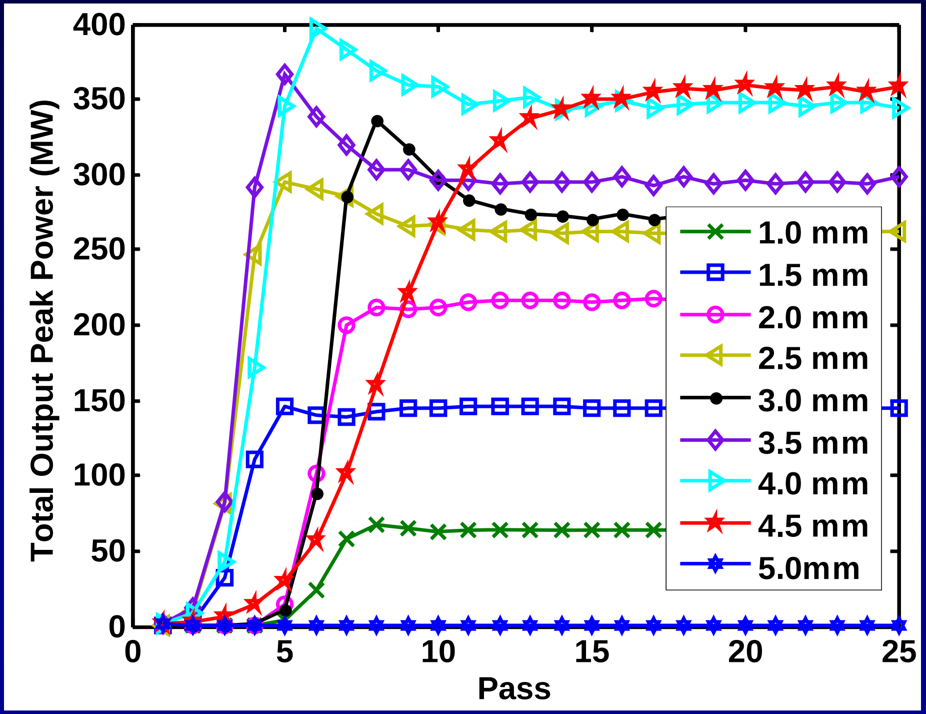


4mm hole: output through hole



Varying hole size





Parameter Summary

Typical ΔvΔt

DESCRIPTION	
FEL design	Regenerative Amplifier
Seeding type	Self-seeding
Seeding mechanism	Low-Q cavity
PHOTON OUTPUT	
Tuning Range	3 - 10 eV
Peak Power	500 - 300 MW (3 GW*)
Repetition rate	$n \times 4\frac{1}{3}$ MHz (n is integer)
Polarisation	Variable elliptical
Min Pulse length FWHM	170 fs (25 fs*)
Typical $\Delta\nu\Delta t$	~1.0
Max pulse energy	70 μJ
Maximum Average output power	$n \times 300$ W

The End

Parameters for RAFEL regime

- 75% outcoupling
- **Output power > 400MW**
- Lower reflectivity = more power
- Saturation in 7 passes