THE USE OF HHG AT 4GLS

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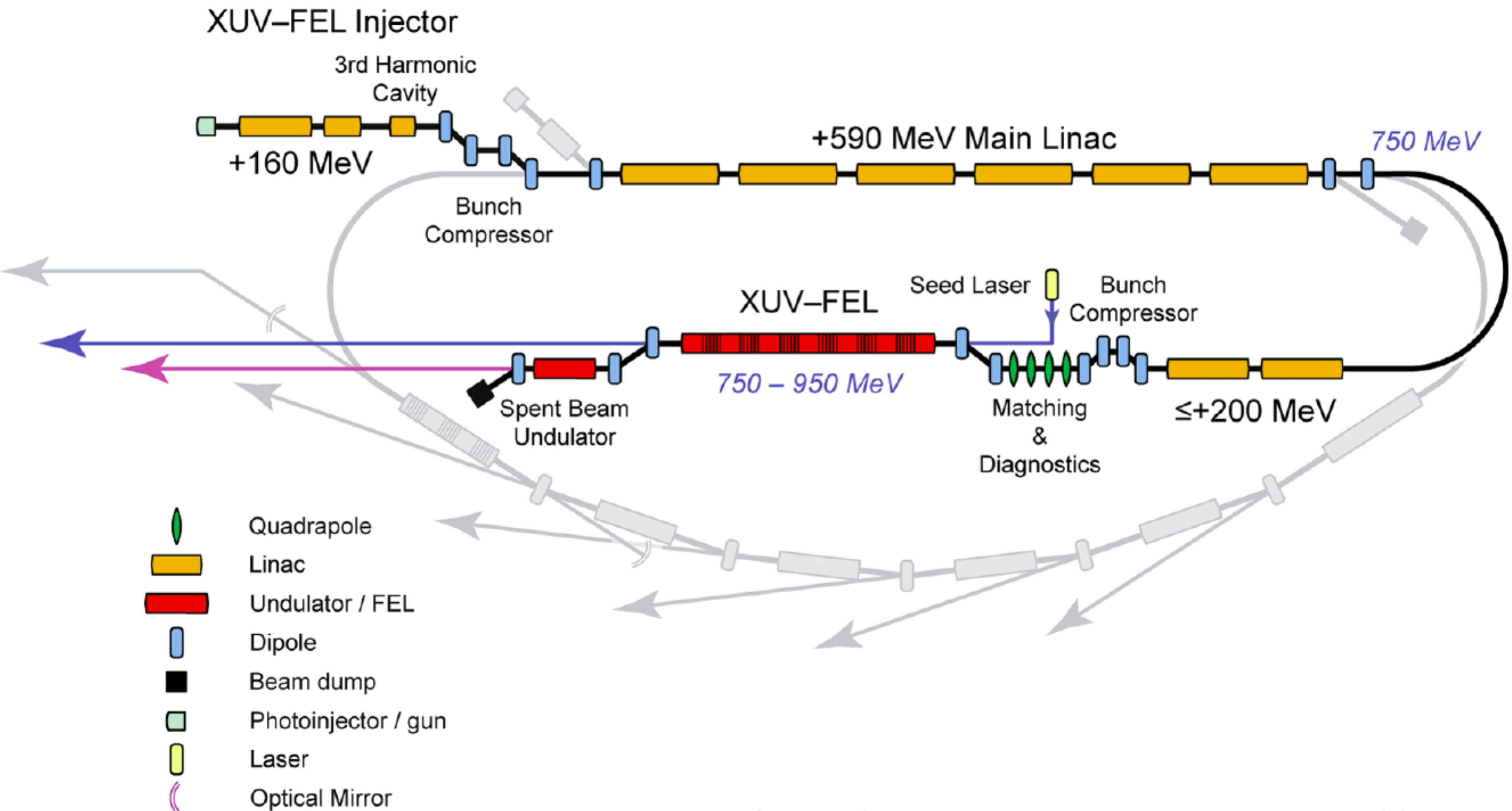
Outline

- Brief look at conceptual design of 4GLS XUV-FEL
- Benefits of amplifier seeding
- 4GLS HHG conceptual design seeding scheme
- Modelling HHG seeding
- Simulations of XUV-FEL conceptual design
- Further design work for XUV-FEL

Conceptual Design of 4GLS XUV-FEL

XUV-FEL layout



I_{pk}=1.5kA ; Q=1nC ; ε_n = 2 mm-mrad ; σ_γ=0.1%

XUV-FEL parameter summary

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General	
FEL design	High Gain Amplifier
Seeding mechanism	HHG source
Photon output	
Tuning Range	$\sim$ 8 - 100 eV
Peak Power	$\sim$ 8 - 2 GW
Repetition rate	$\sim$ 1 kHz
Polarisation	Variable elliptical
Min Pulse length FWHM	$<$ 50 fs
Typical $\Delta f \Delta t$	$\sim$ 0.6
Max pulse energy	400 μJ
Electron beam parameters	
Energy	750 - 950 MeV
Bunch Charge	1 nC
RMS bunch length	266 fs
Normalised emittance	2 π mm mrad
RMS energy spread	0.1%
Undulator parameters	
Undulator Type	PPM & APPLE-II
No of Modules	8 & 5
Module lengths	$\sim$ 2 m
Period	45 mm & 51 mm
Focusing	FODO
Minimum magnetic gap	$\sim$ 10 mm

XUV FEL Undulator Tuning: Variable Polarisation Options

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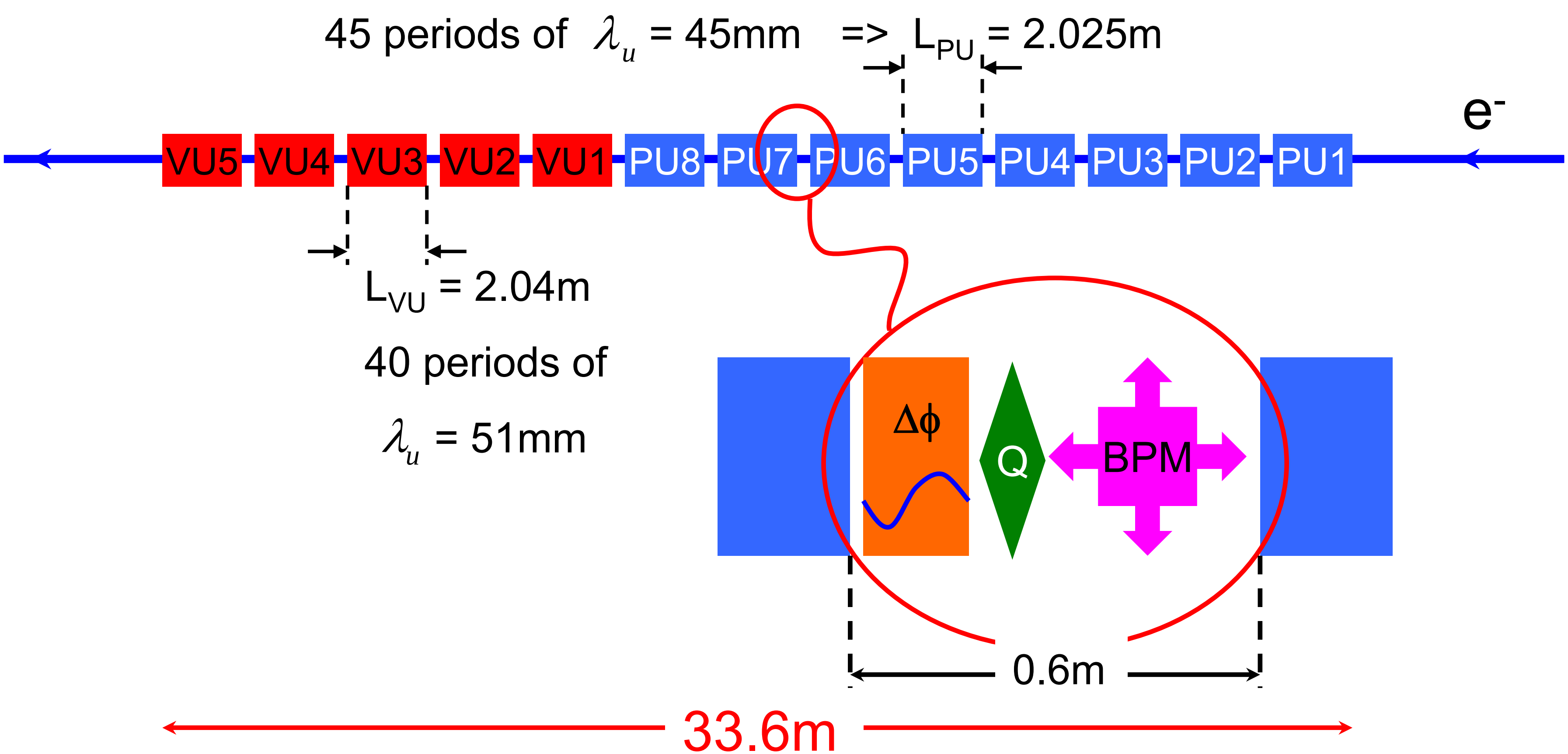
- OPTION 1: baseline design
  - **10-100eV**
  - 10mm min gap
  - W1 planar 45mm period
  - W2 APPLE II 51mm period
- OPTION 2: extension to 6eV
  - **6-100eV**
  - 8mm min gap
  - W1 planar 45mm period
  - W2 APPLE II 53mm period
- OPTION 3: extension to 6eV
  - **6-100eV**
  - 10mm min gap
  - W1 planar 45mm period
  - W2 APPLE II 57mm period

"Gaps" are undulator gaps

⇒Vacuum gaps will be

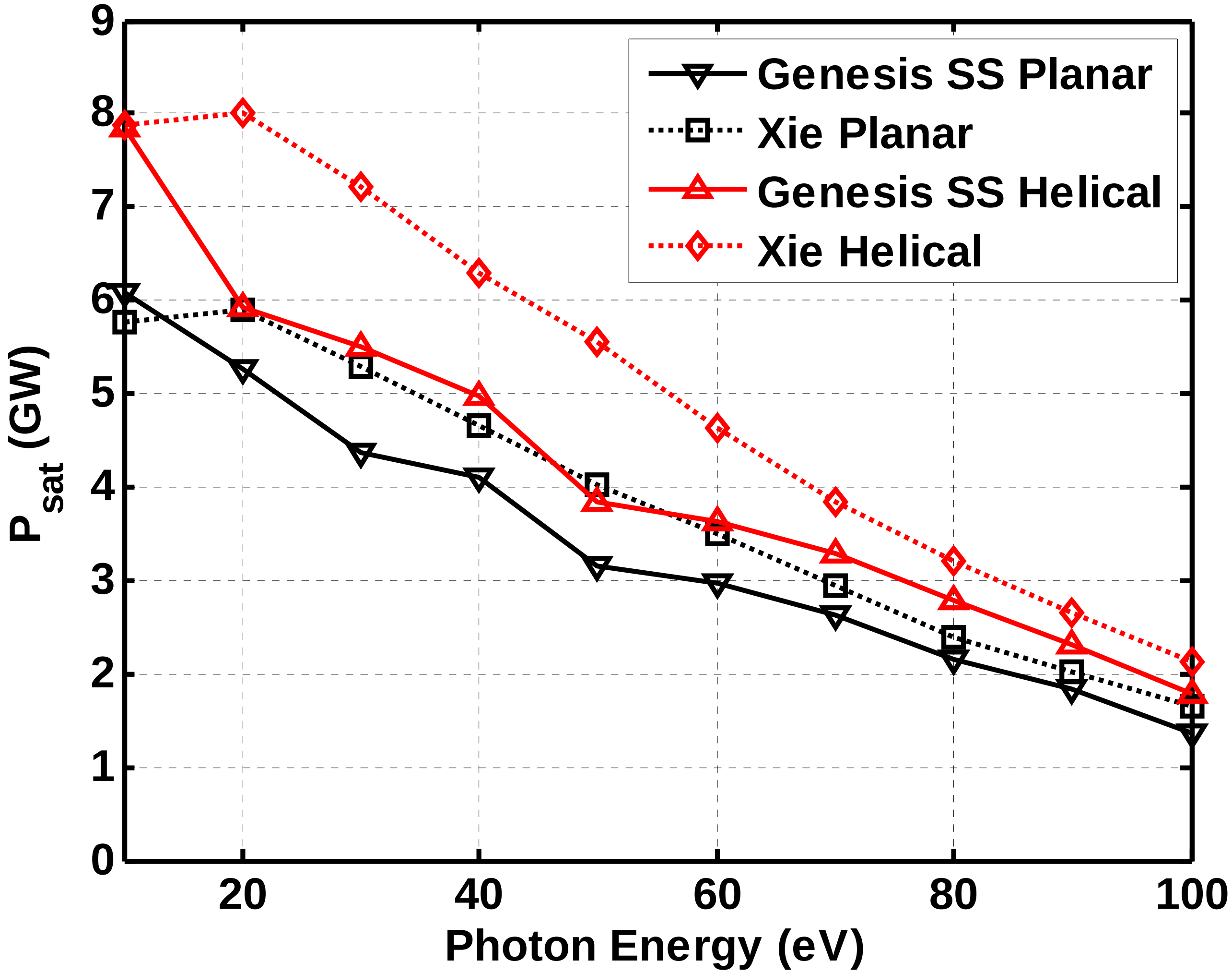
~ undulator gaps – 3mm

Baseline Option 1*
(10-100eV; 10mm gap)



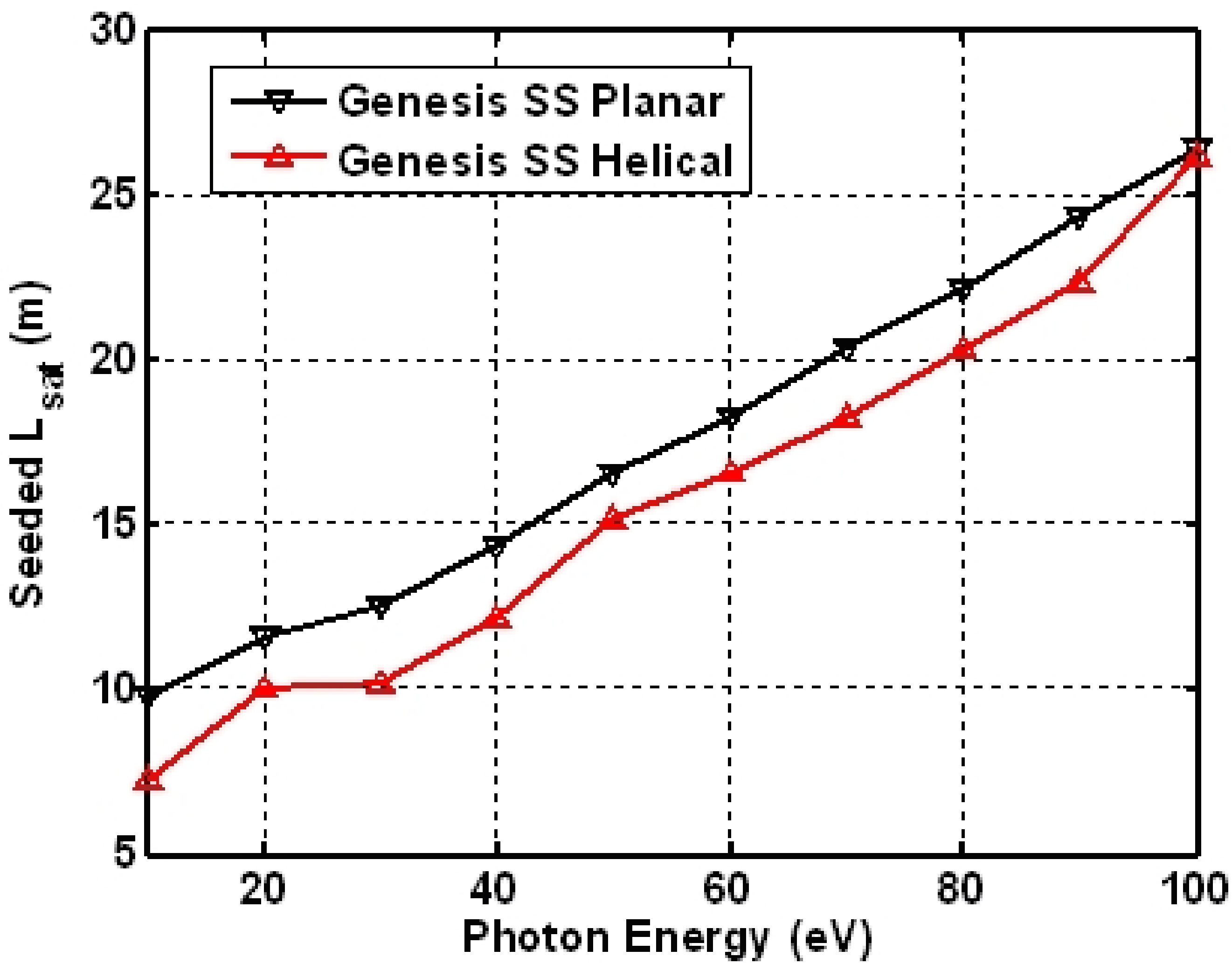
BWJ McNeil, NR Thompson & B Sheehy, These proceedings - MOPPH012

SS Simulations 10-100eV



SS Simulations 10-100eV

Undulator length – no gaps



Benefits of amplifier seeding

- Improvement in the temporal coherence (and hence spectral brightness)
- Shot-to-shot reproducability (same shape)
- Shot-to-shot stability (same power)
- Shorter pulses – not determined electron pulse
- Shorter interaction length (& cost)
- Amplify exotic pulses for post-amplification manipulation
- Seed may be used as source in its own right
- Requires spatio-temporal synchronisation with electrons

4GLS HHG conceptual design seeding scheme

MODULES REQUIRED 10-100eV

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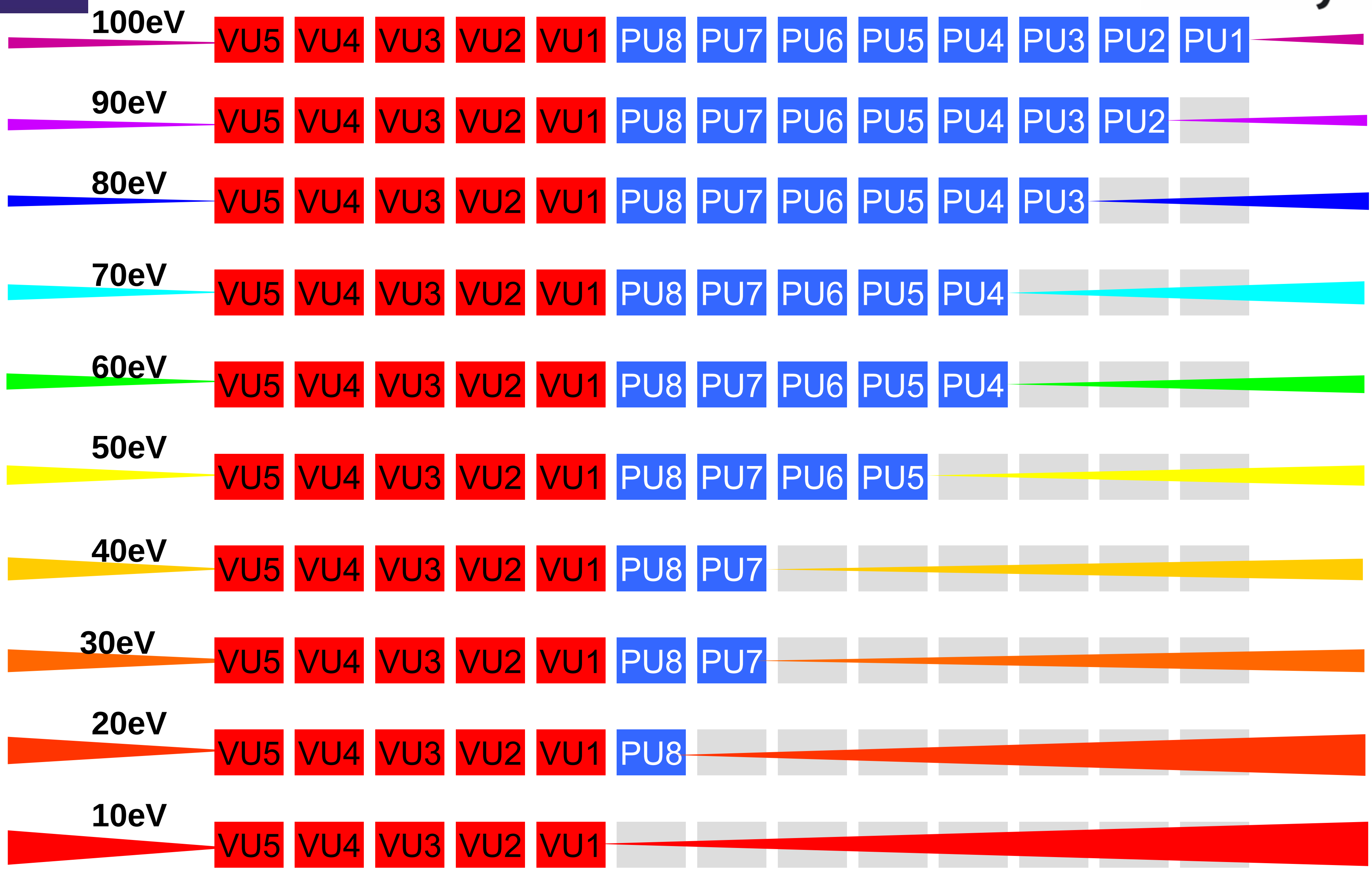
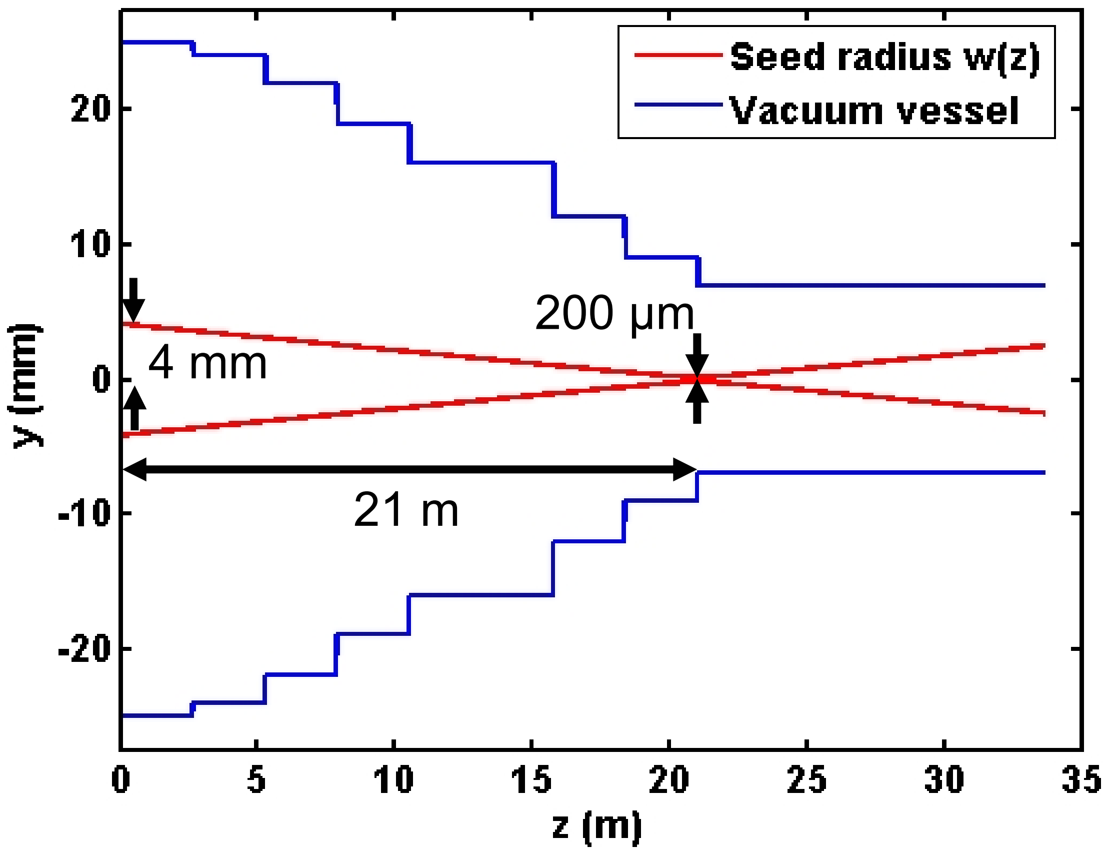
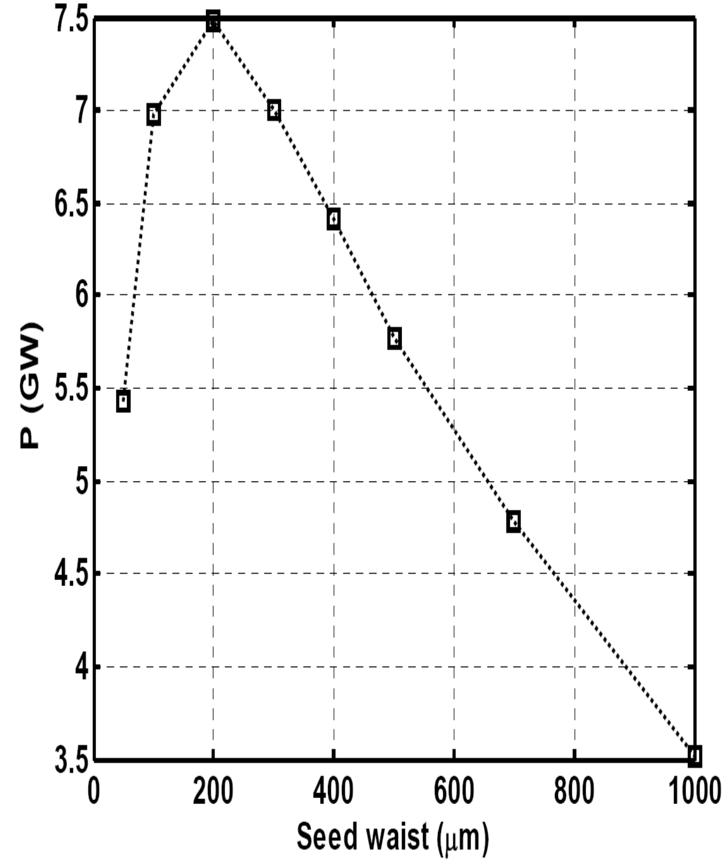


Tapered vacuum vessel

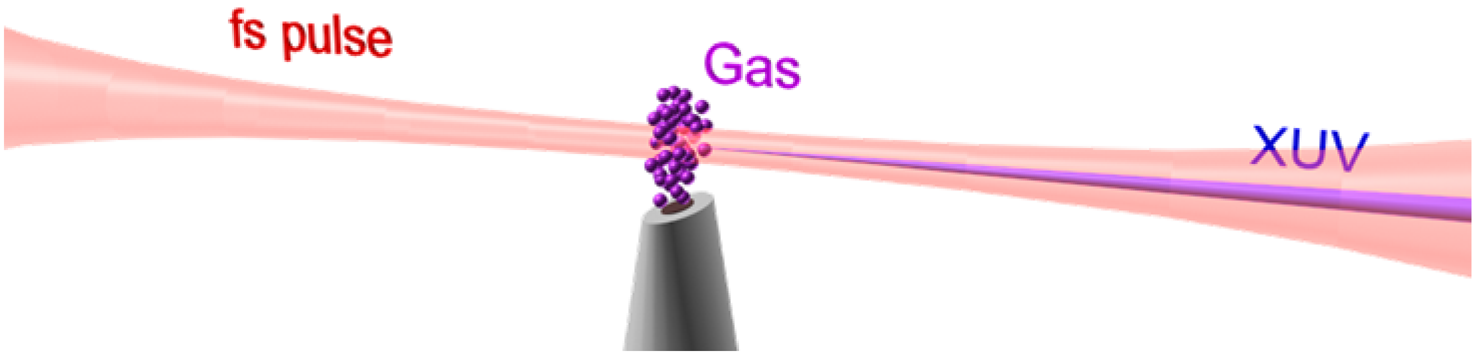


Saturation power



$$w(z) = w_0\sqrt{1+\left(\frac{z-z_0}{Z_R}\right)^2} \qquad Z_R = \pi w_0^2/\lambda$$

HHG Seed Generation



Good introductory source material at:
Henry C. Kapteyn et al., “EUV ‘Photonics’ of High-Harmonic Generation and Applications “
ICFA Beam Dynamics Mini Workshop (Future Light Source Working Group)
Workshop on the Physics of Seeded Free Electron Lasers
MIT, 17-19 June 2004 (http://mitbates.mit.edu/xfel/conference.htm)

and:
John W.G. Tisch, “Alternative Coherent X-ray Sources”,
STI Round-Table Meeting DESY,
Hamburg 22-24 June 2004
(xfel.desy.de/content/e154/upload/upload_file/Meetings/STI_June04/Tisch.pdf)

HHG Energy Spectrum*

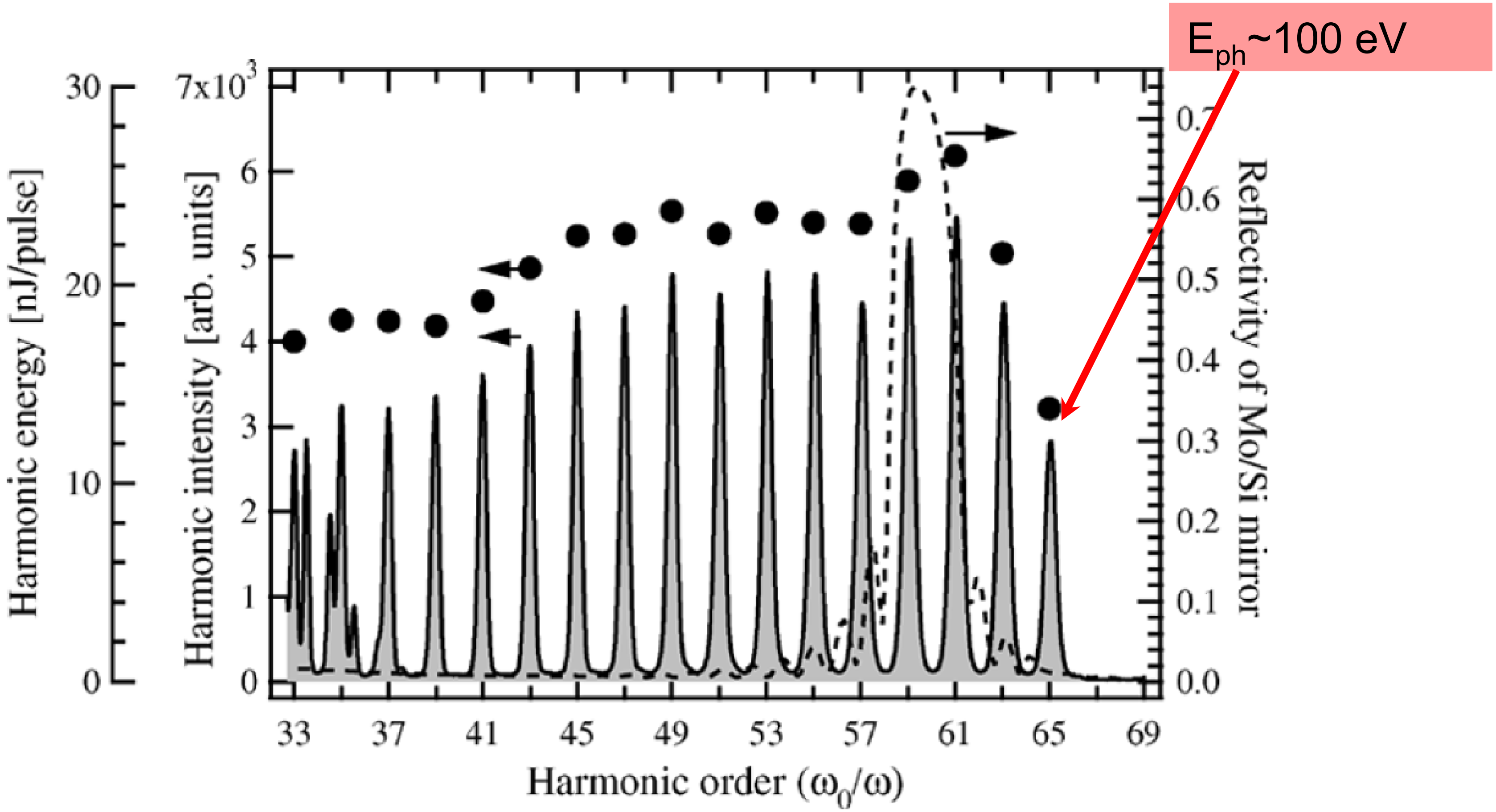
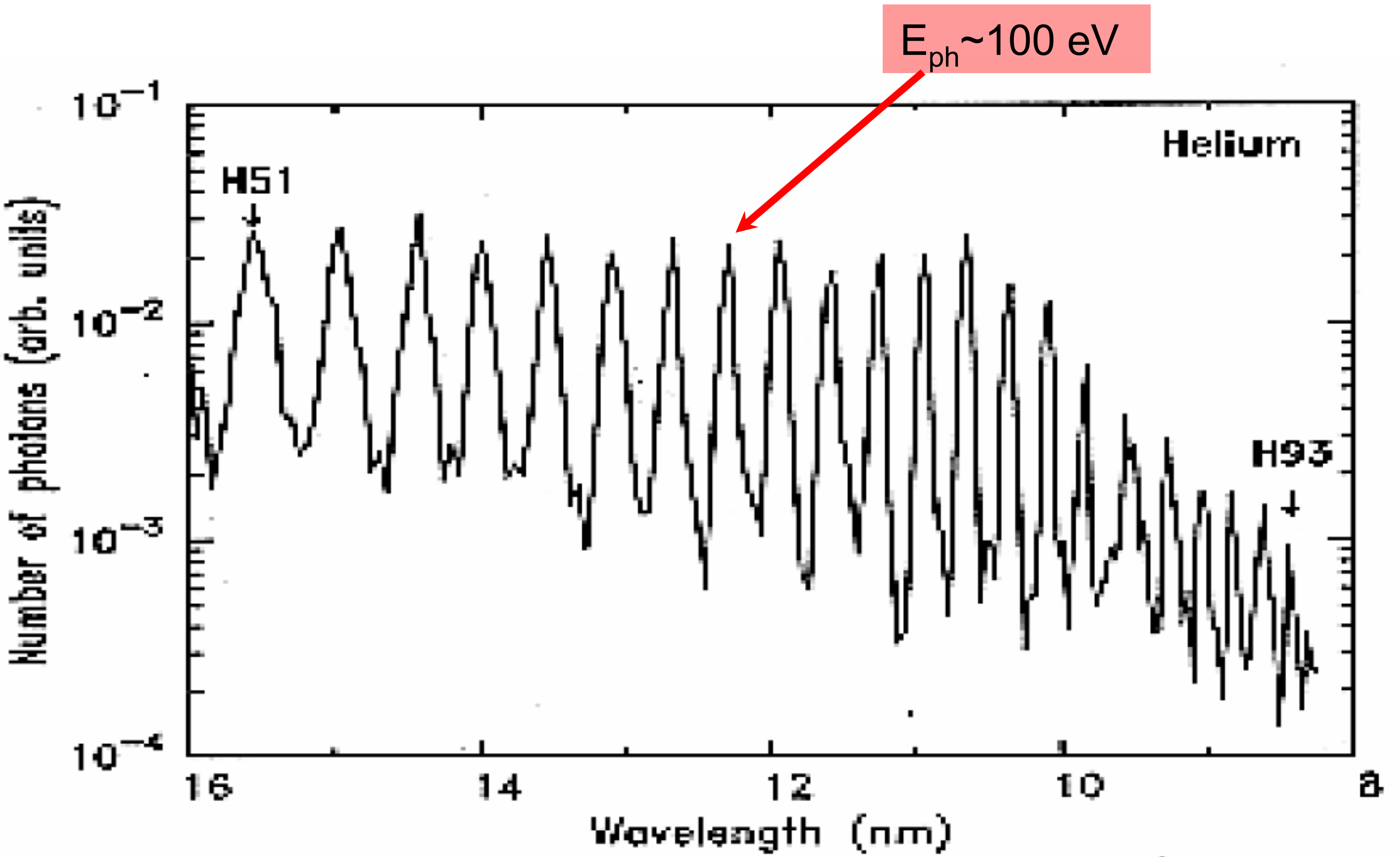


Fig. 9. Experimentally obtained harmonic spectra and energy yield in Ne gas. Dotted line shows the reflectivity of Mo–Si multilayer mirror.

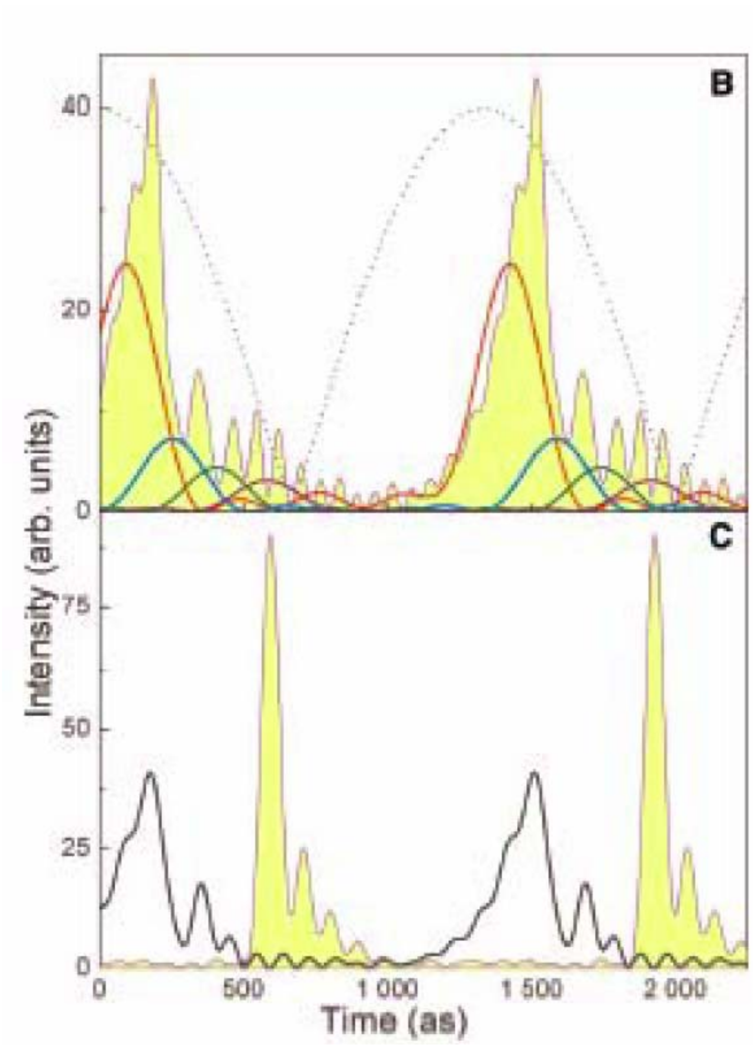
*Eiji J. Takahashi et al., IEEE Journal of Selected Topics in Quantum Electronics, **10**, 1315 (2004)

HHG Energy Spectrum*



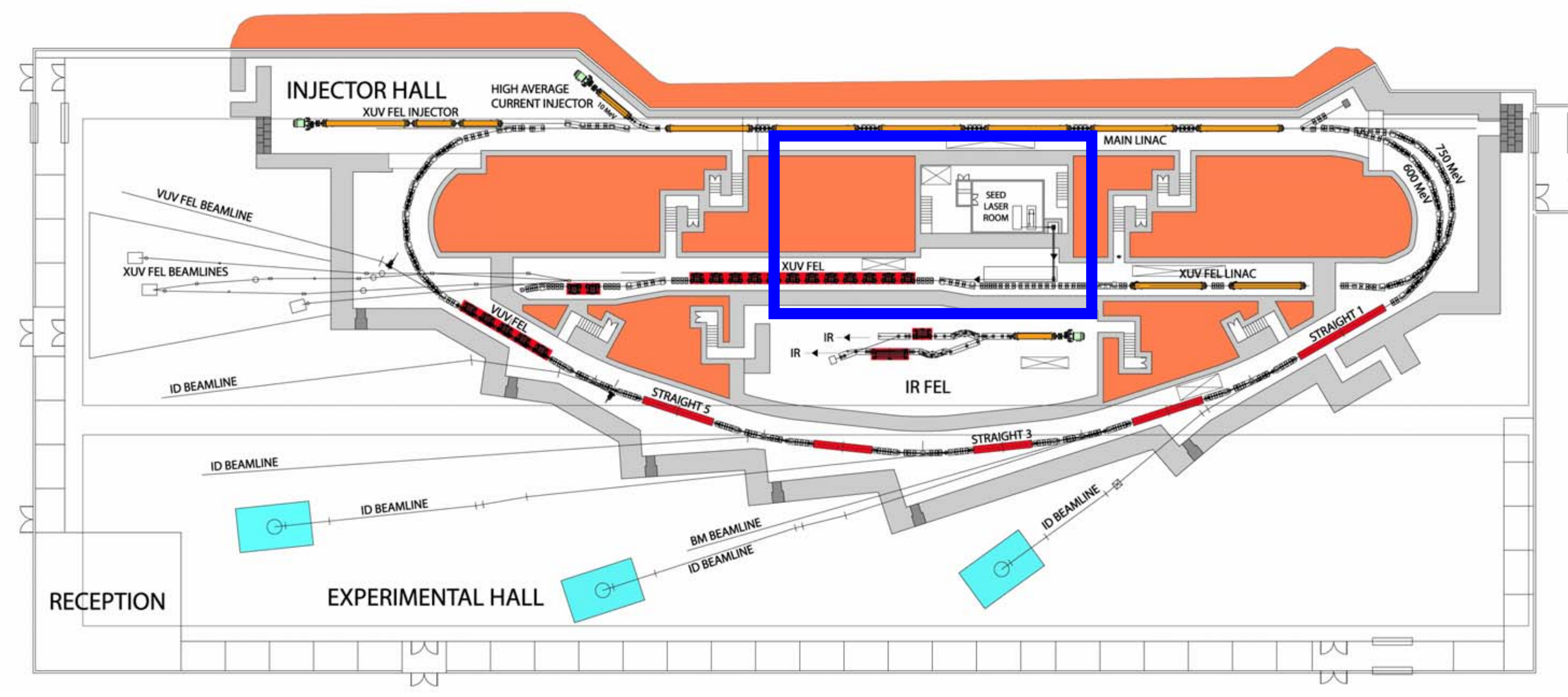
*Y. Mairesse et al., Science **302**, 1540 (2003)

HHG temporal structure



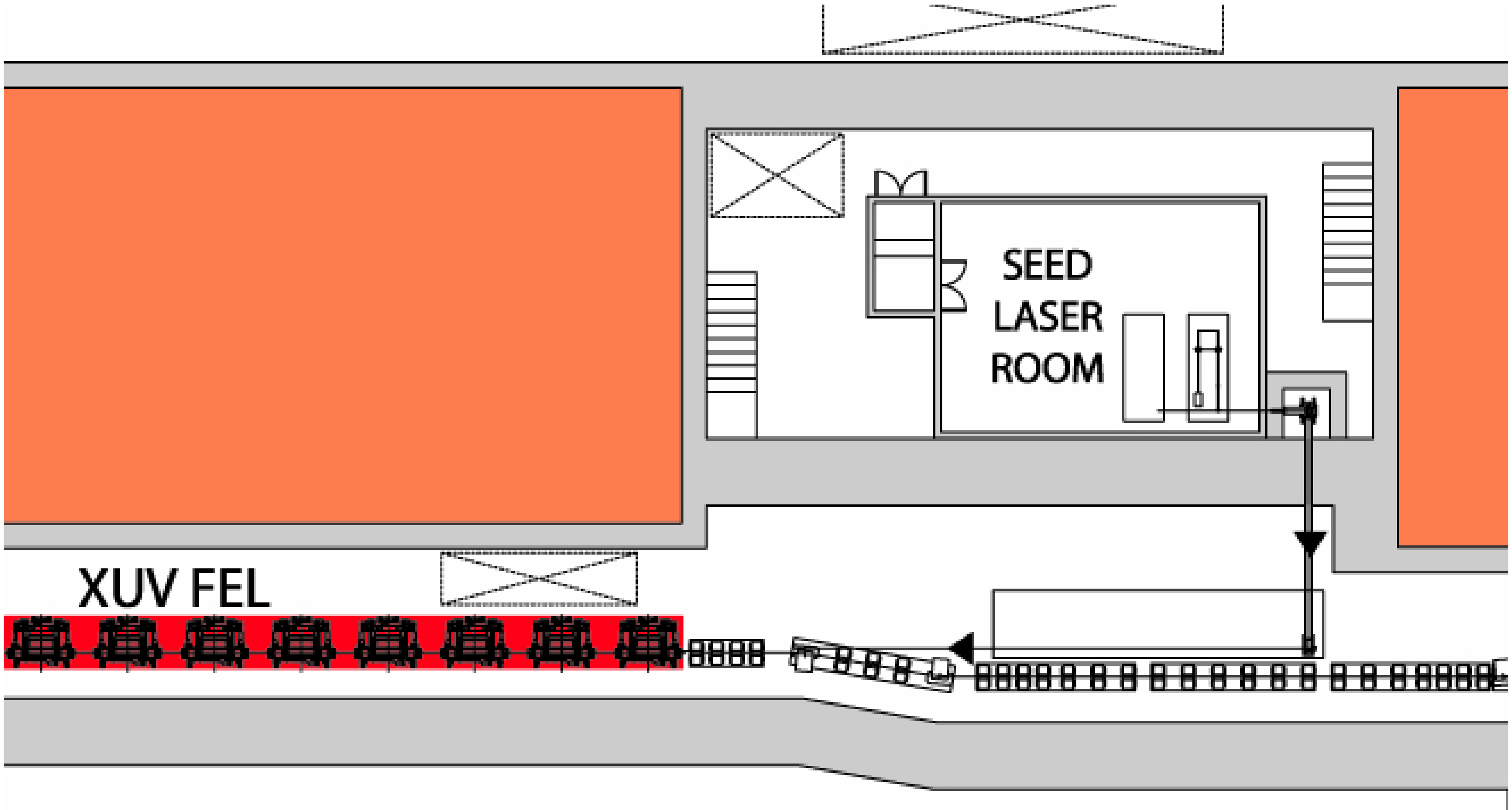
Temporal structure contains a series of atto-second spikes separated by ½ of the drive laser period

4GLS layout

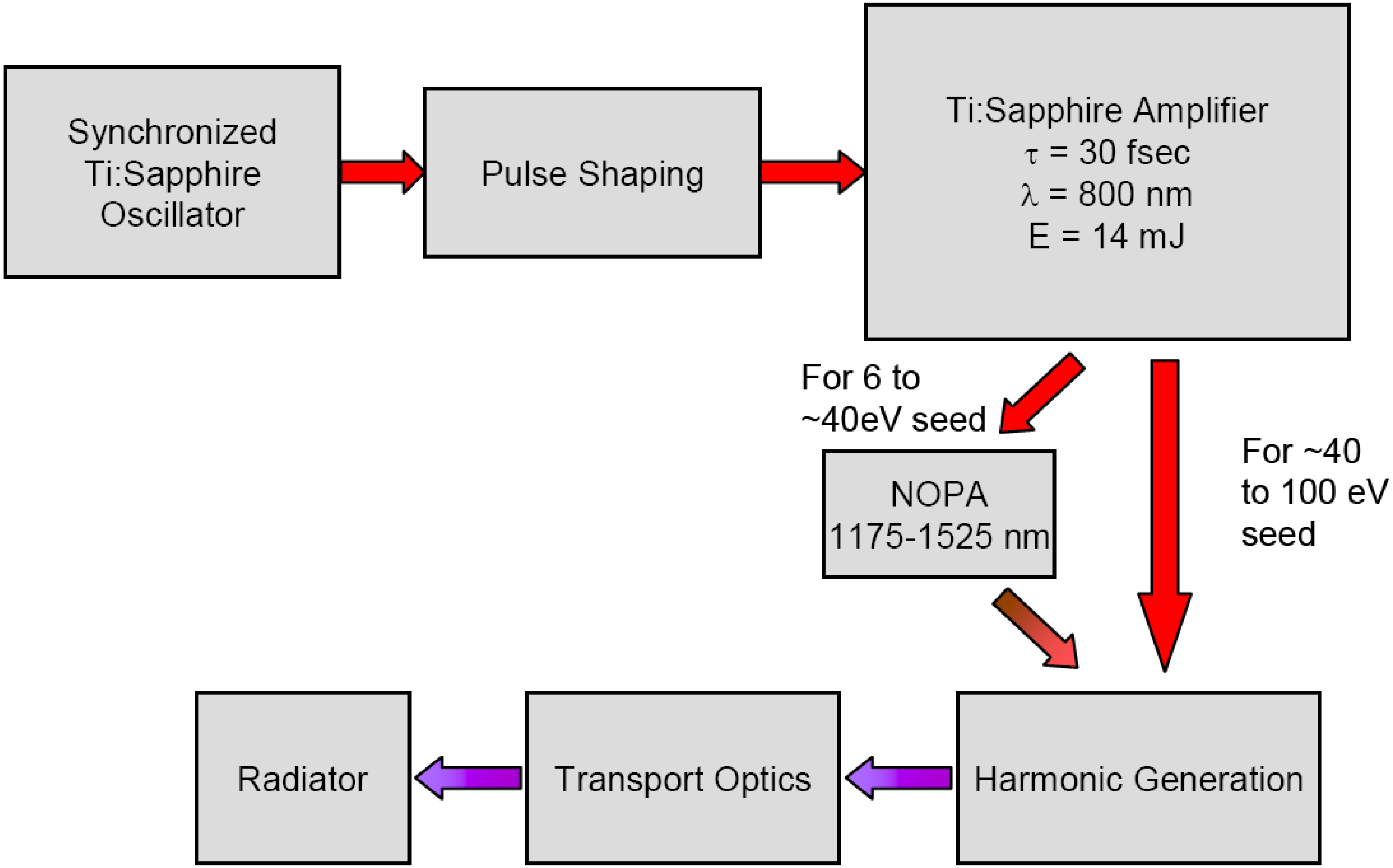


INJECTOR HALL
HIGH AVERAGE
CURRENT INJECTOR
XUV FEL INJECTOR
10 MeV
MAIN LINAC
750 MeV
600 MeV
SEED
LASER
ROOM
VUV FEL BEAMLINE
XUV FEL BEAMLINES
XUV FEL
XUV FEL LINAC
VUV FEL
IR
IR
IR FEL
STRAIGHT 1
STRAIGHT 5
STRAIGHT 3
ID BEAMLINE
ID BEAMLINE
ID BEAMLINE
BM BEAMLINE
ID BEAMLINE
ID BEAMLINE
RECEPTION
EXPERIMENTAL HALL

Seed laser room



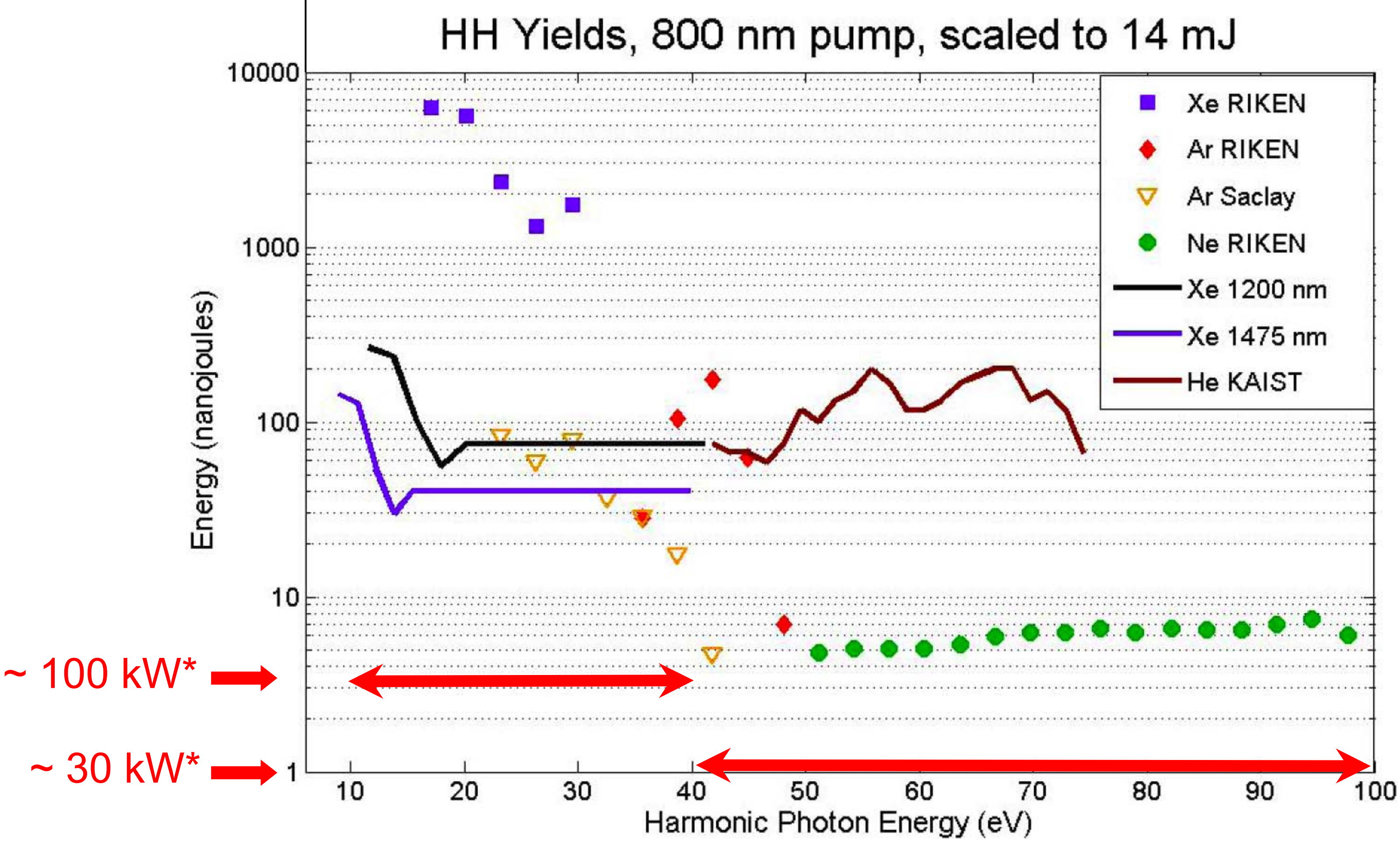
HHG seed for XUV-FEL



See: B. Sheehy et al., this conference: MOPPH067

~3 GW X

Seed energy



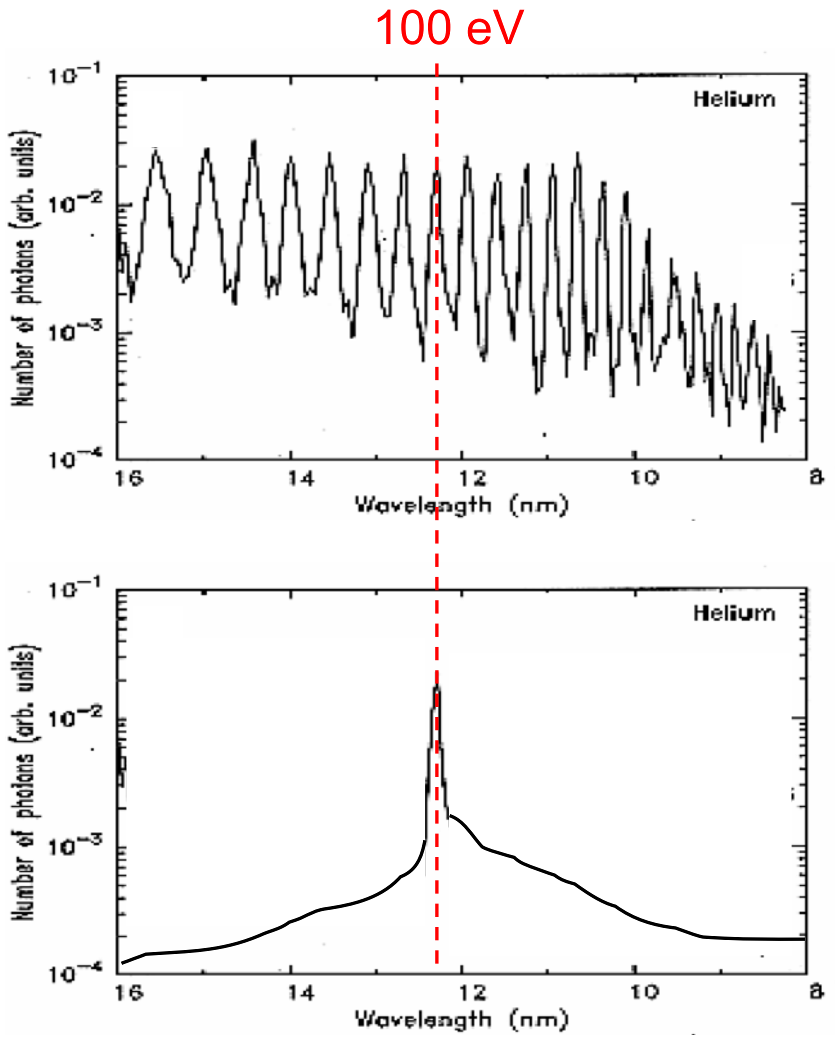
*For 30 fs FWHM – The peak powers used for XUV simulations

Modelling HHG seeding

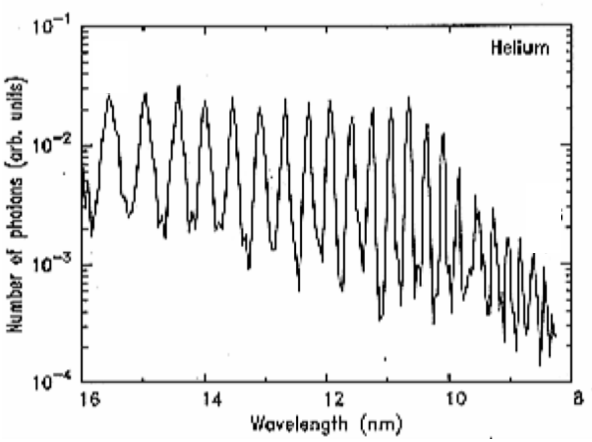
Seeding options

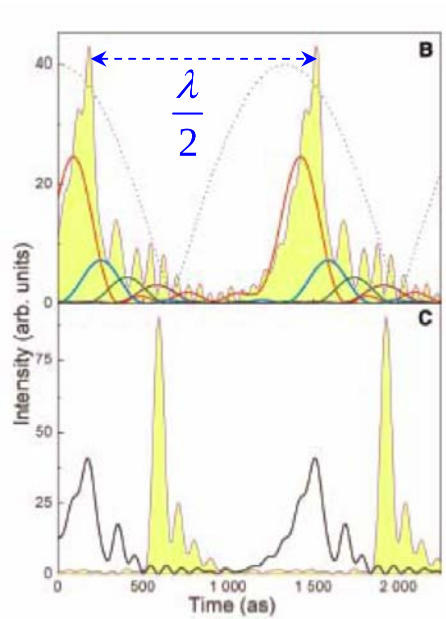
1) Un-filtered ?

2) Filtered ?



Un-filtered expectations





1) Spectral:

FEL gain bandwidth < harmonic separation

$$\left.\frac{\Delta\lambda_n}{\lambda_n}\right|_{HWHM} \sim \rho \qquad \frac{\Delta\lambda_n}{\lambda_n} \approx \frac{1}{n}$$

$$\rho < \frac{1}{n}$$

$$\rho \approx 2\times10^{-3}$$

$$n^{-1} \approx 1.5\times10^{-2}$$

2) Spatio-temporal:

Distance between spikes < cooperation length

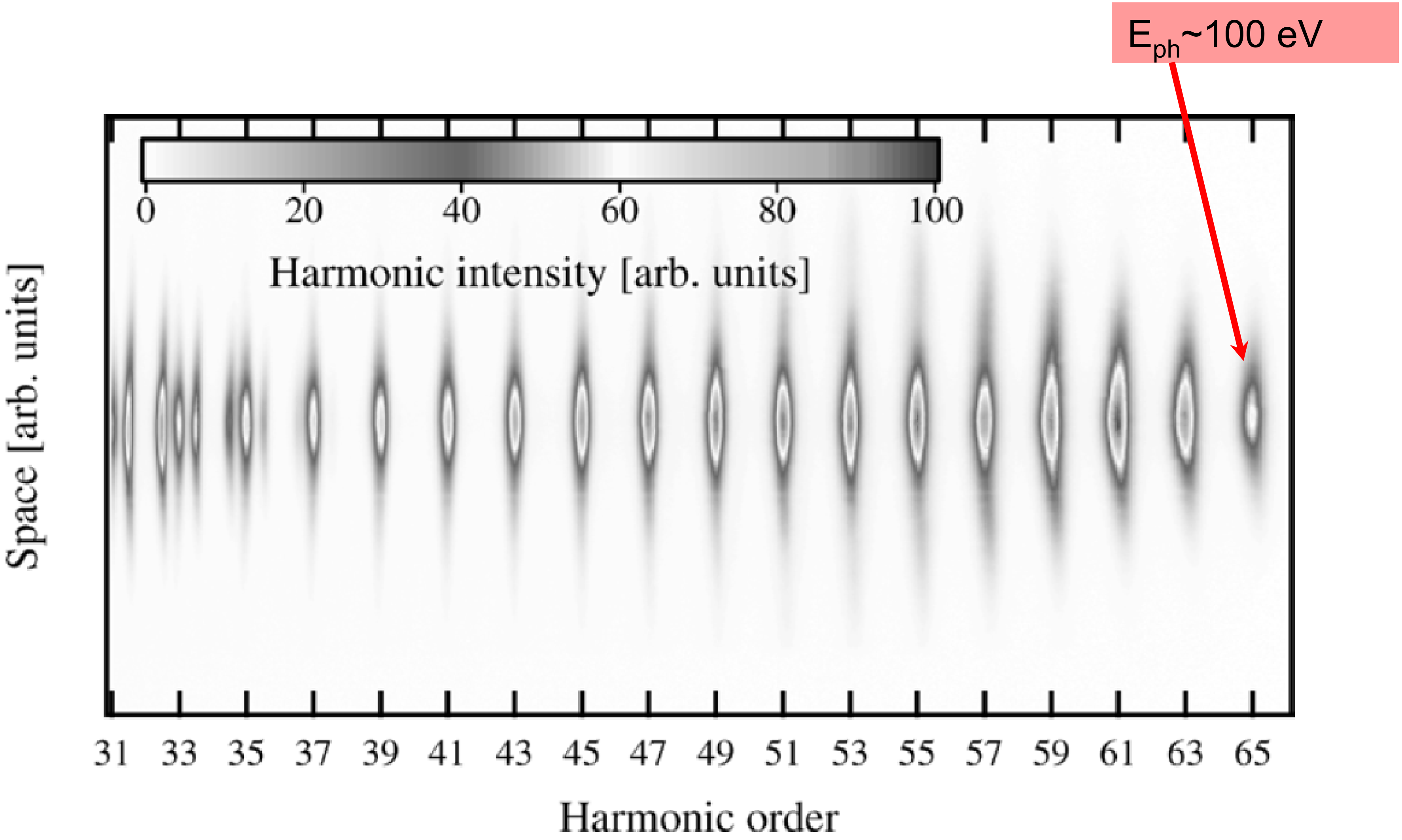
$$\frac{\lambda_1}{2} \qquad \frac{\lambda_n}{4\pi\rho} = \frac{\lambda_1}{4\pi\rho n}$$

$$\rho < \frac{1}{2\pi n}$$

Not so important if 1) applies as need only consider one resonant harmonic => no short pulse structure

Can neglect all non-resonant harmonics? - Yes

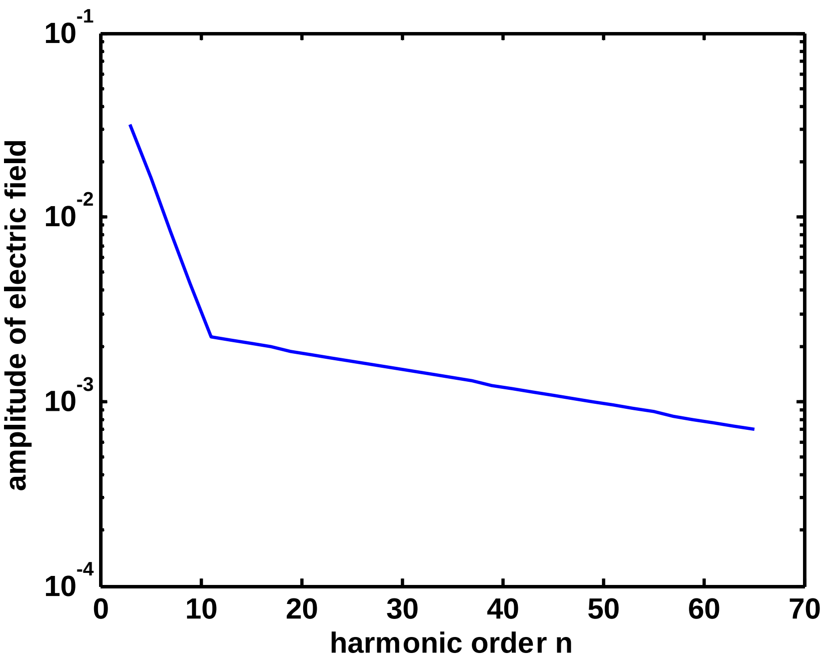
HHG Spectral Intensity*

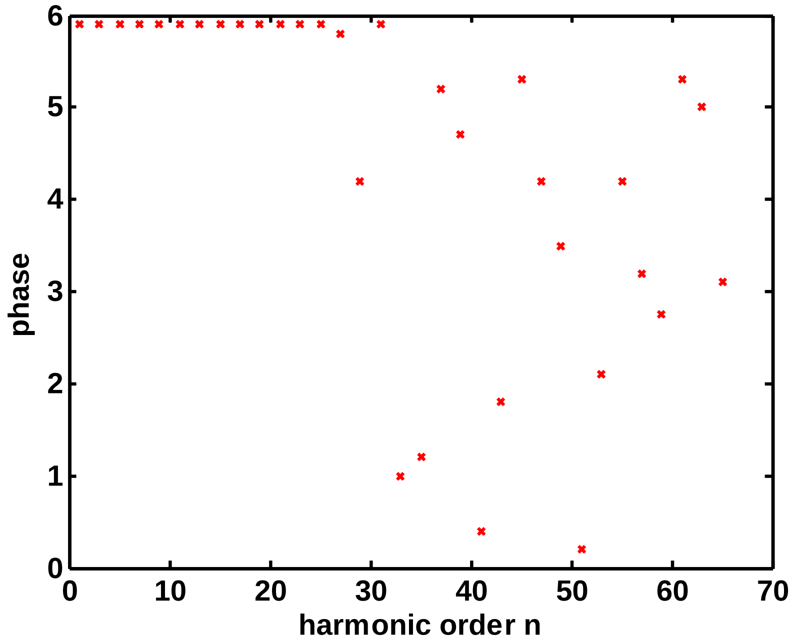


*Eiji J. Takahashi et al., IEEE Journal of Selected Topics in Quantum Electronics, **10**, 1315 (2004)

Simulated electric field

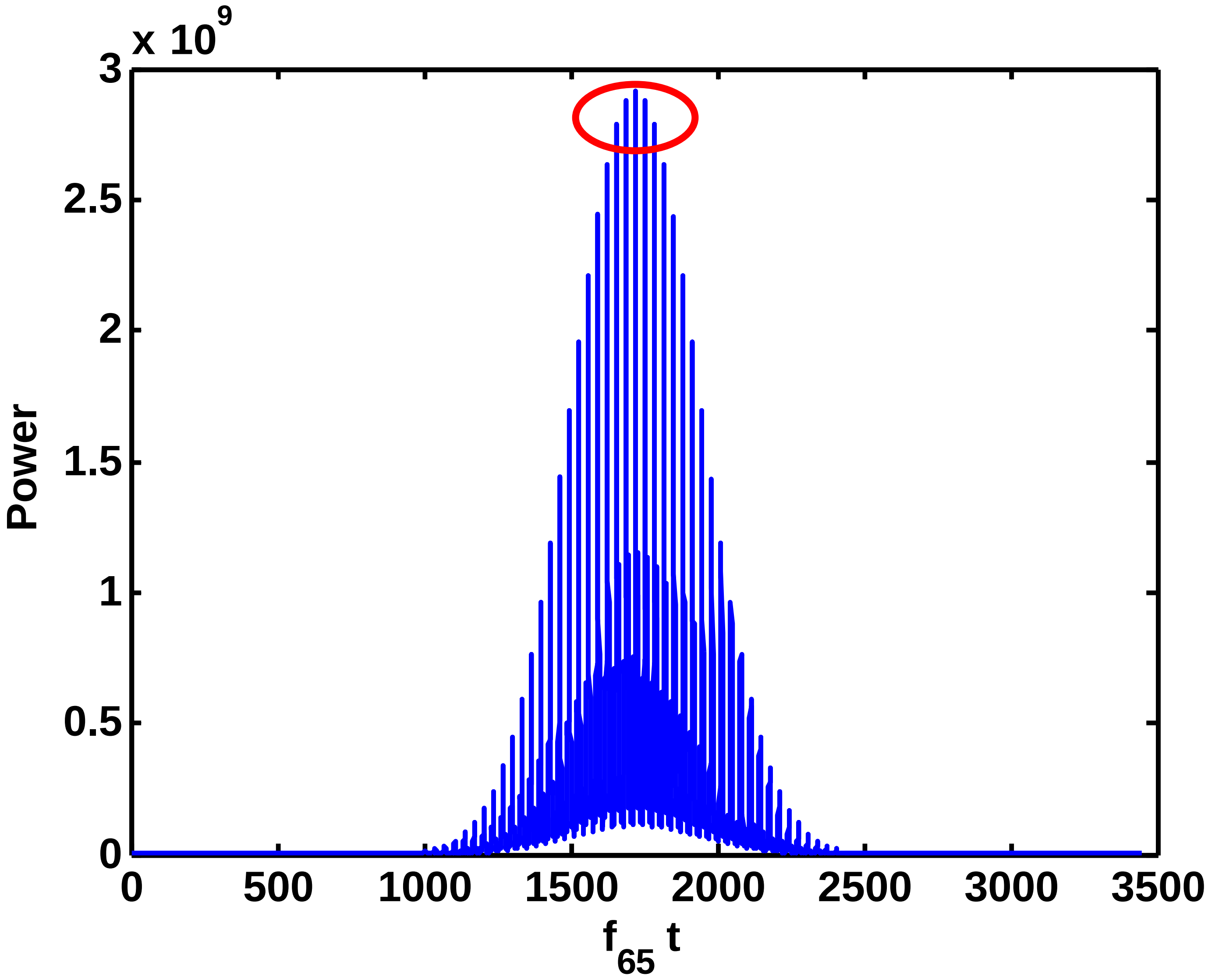
$$E = \sum_{\substack{n=3 \\ odd}}^{65} E_n e^{-i\omega_n t} e^{i\phi_n}$$



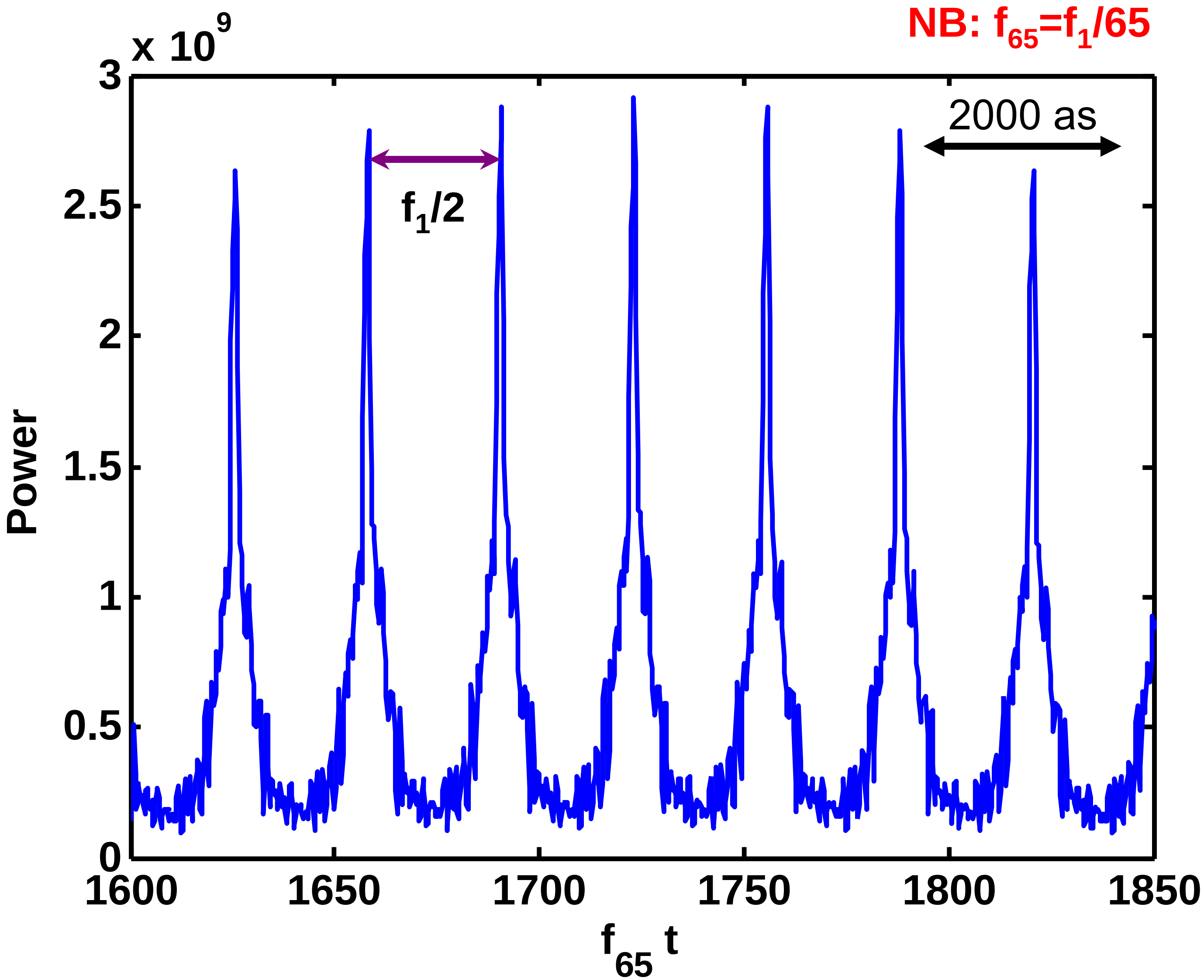


P. Antoine et al., Phys. Rev. A **56**, 4960 (1997)

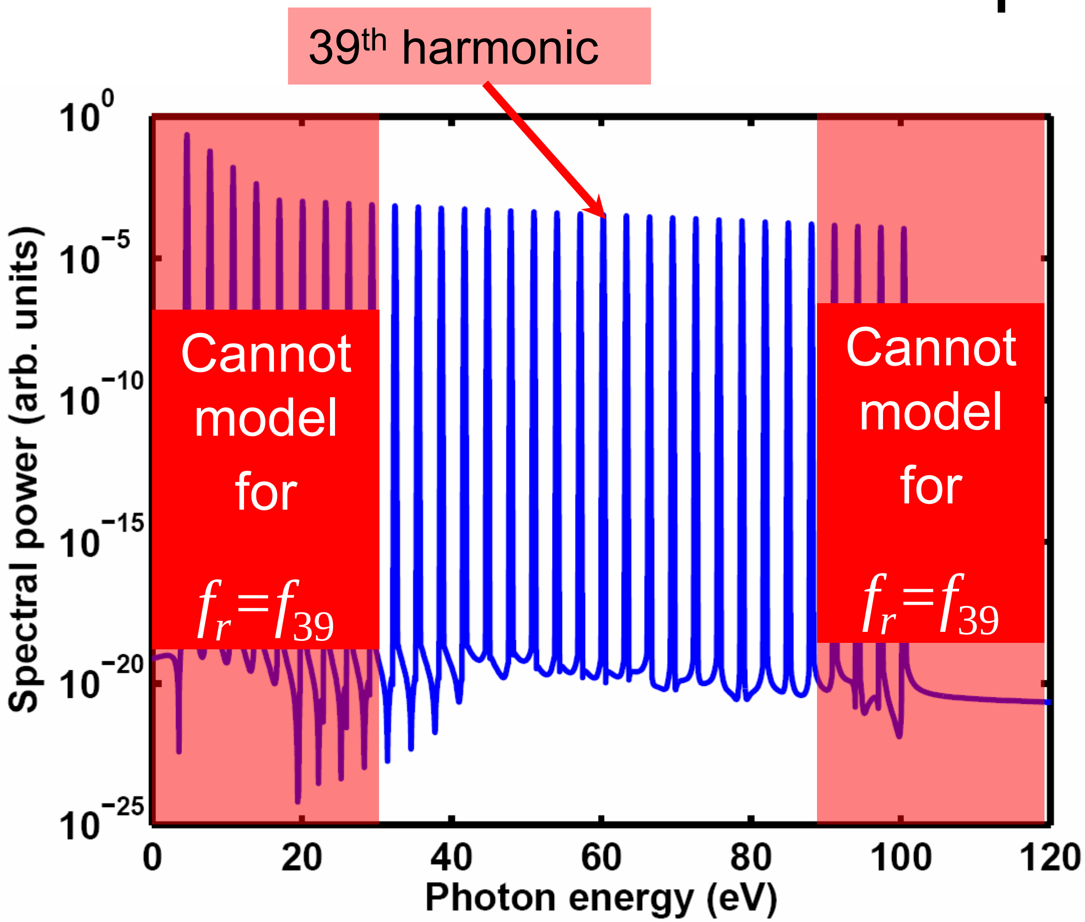
Simulated power



Simulated field detail



Simulated spectrum



For averaged FEL codes the minimum sample rate is:

$$\Delta t_s = f_r^{-1}$$

$$f_{Ny} = \frac{1}{2\Delta t_s} = \frac{1}{2} f_r \quad \text{Nyquist freq.}$$

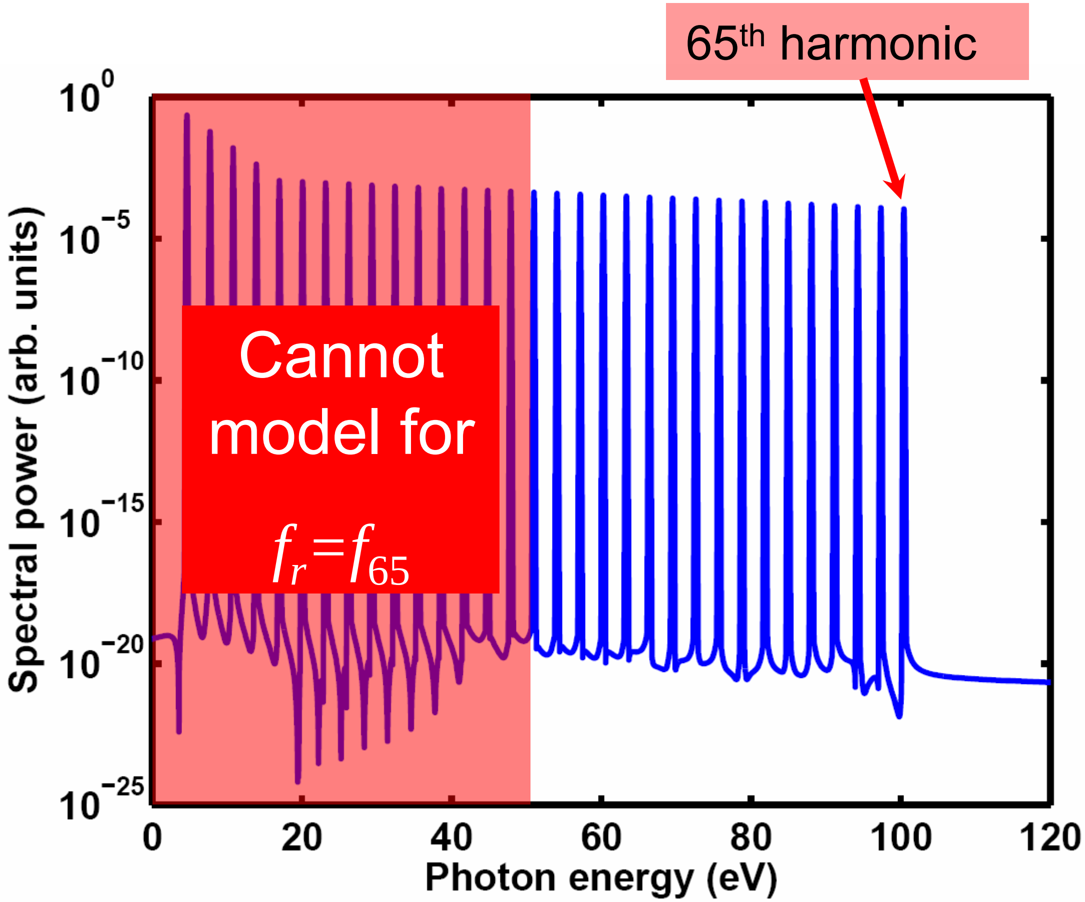
Freq. range for non-aliasing:

$$\left(f_r - f_{Ny} \right) > f_r > \left(f_r + f_{Ny} \right)$$

=> Freq. range that e.g. Genesis can simulate properly without aliasing is:

$$\frac{f_r}{2} > f_r > \frac{3 f_r}{2}$$

Simulated spectrum



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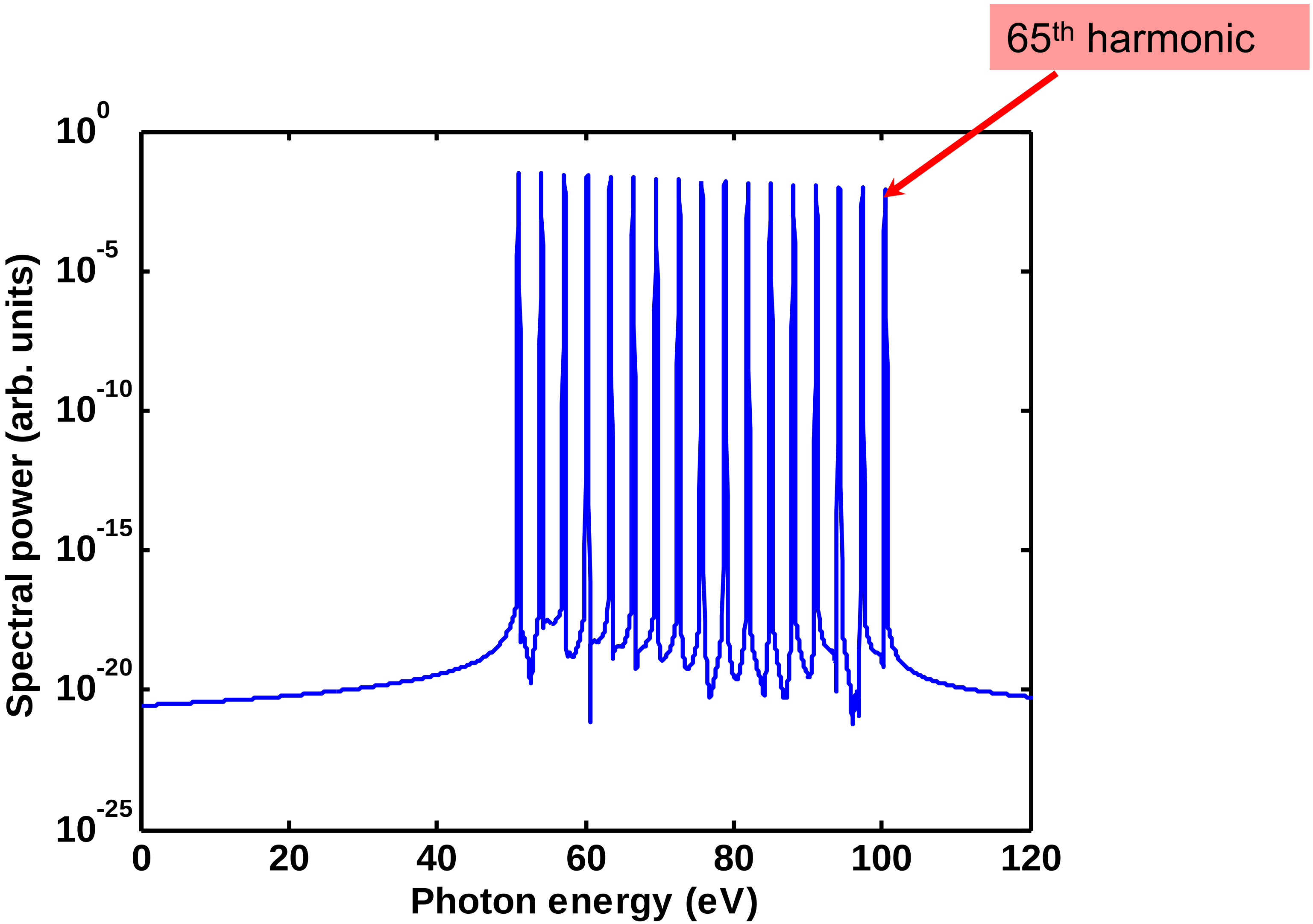
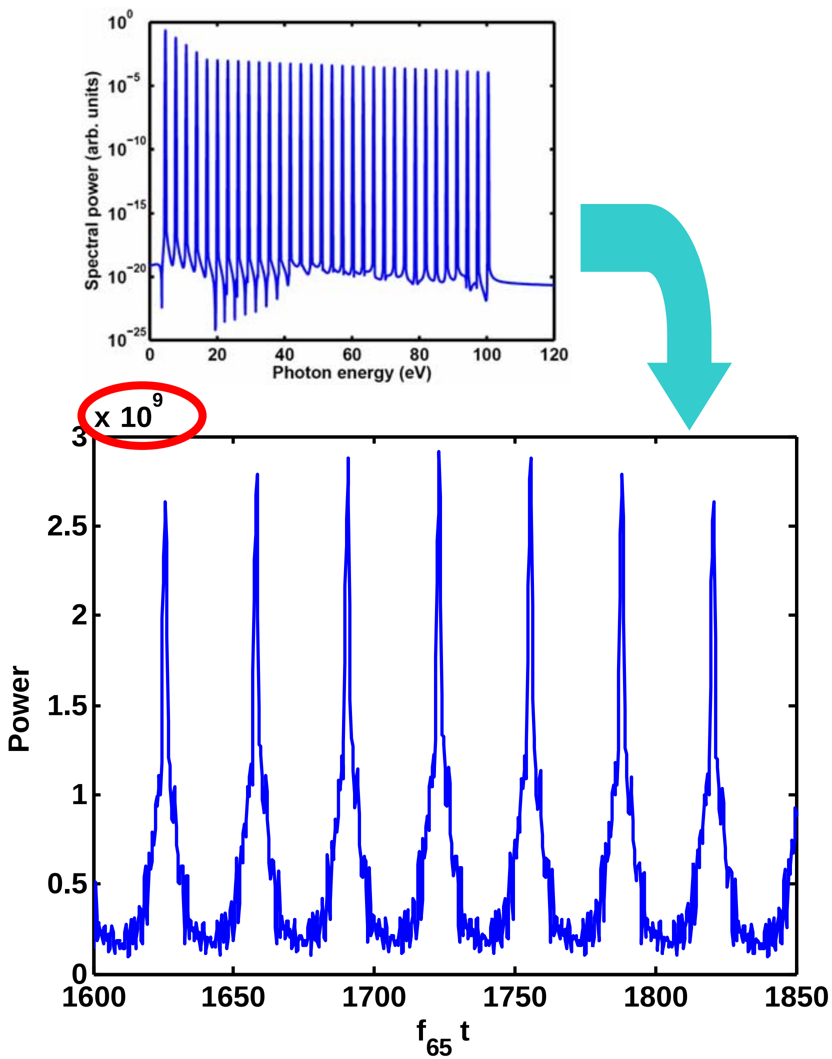
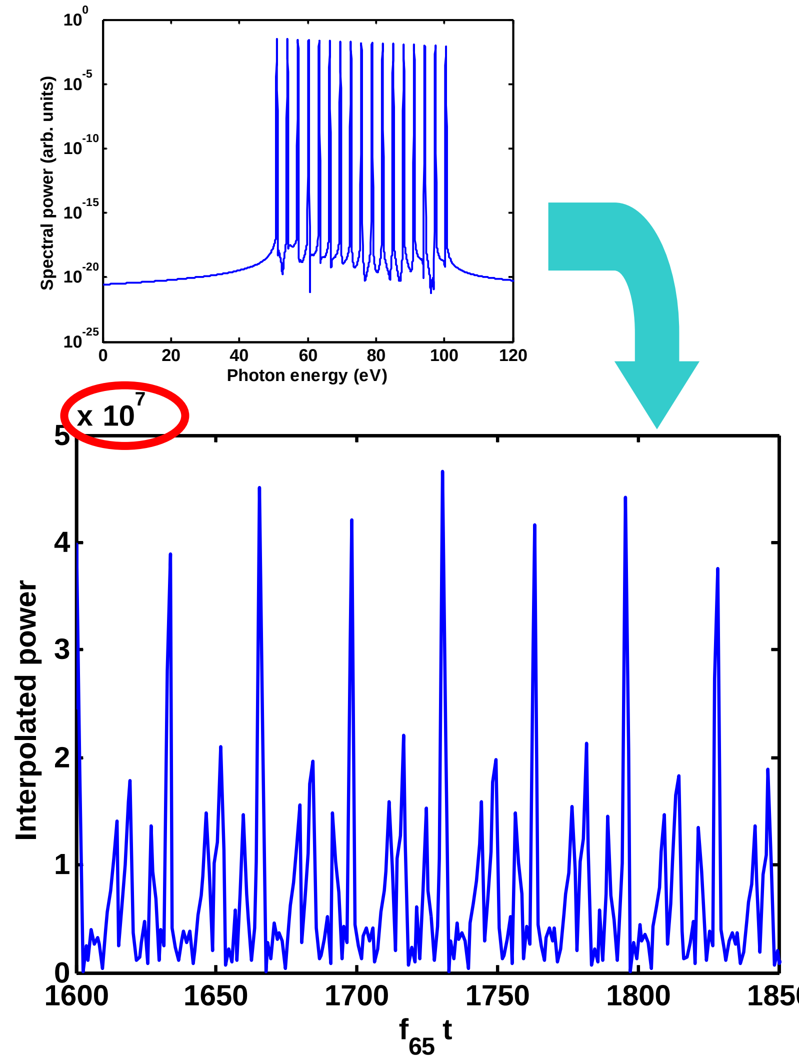
Simulated spectrum



Reality check

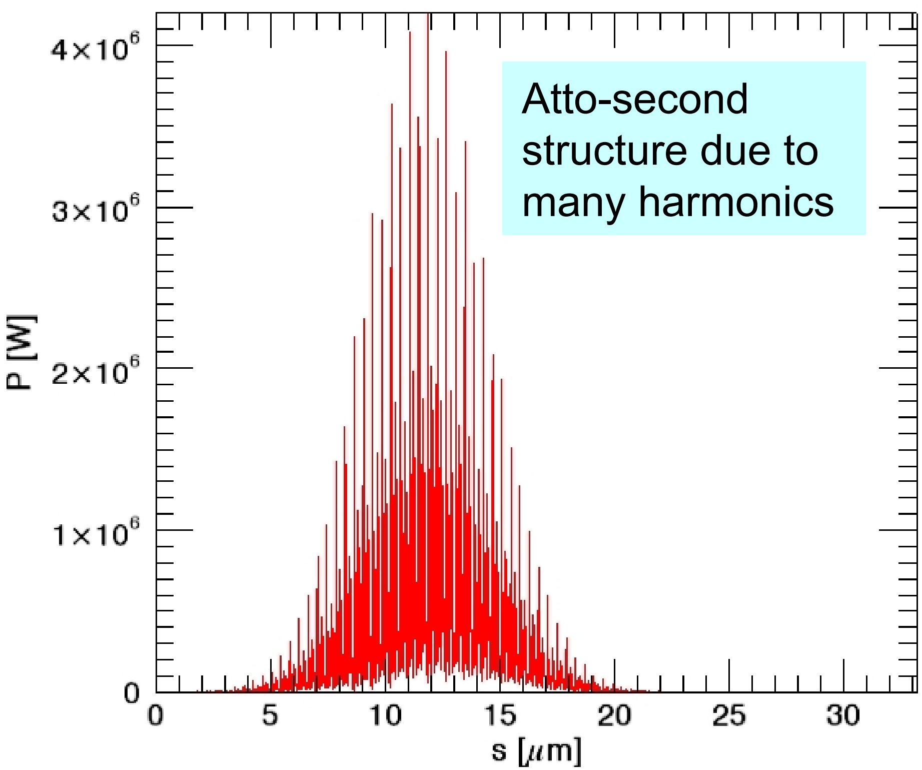


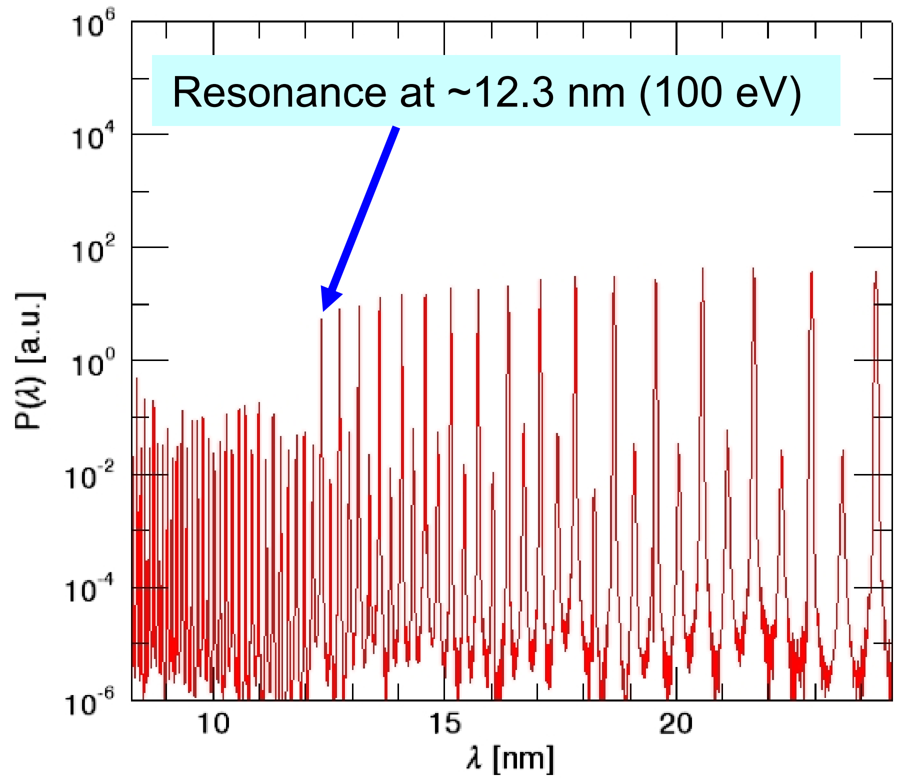
“Reality”



Genesis input

Genesis simulation





HHG seed field at entrance to FEL

XUV-FEL parameters but with uniform current I=1.5 kA

Genesis simulation

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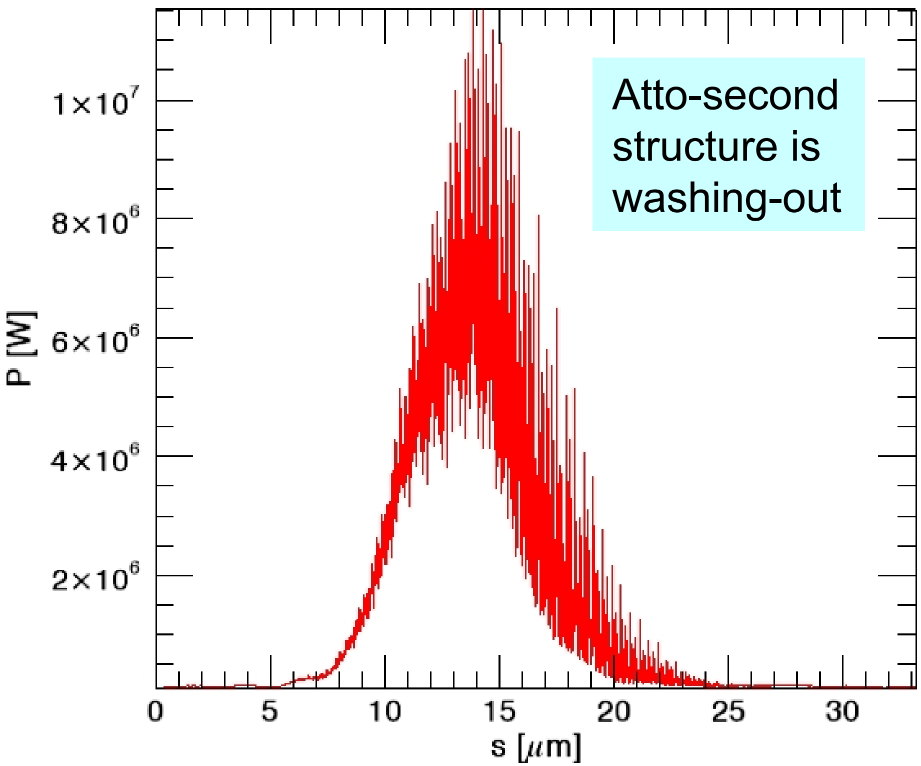
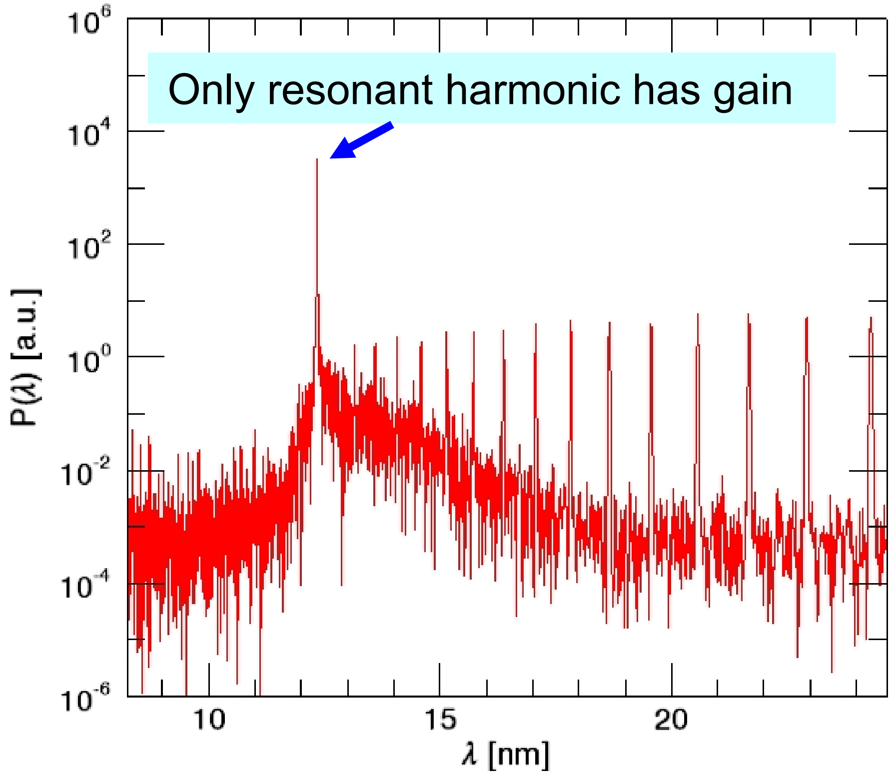
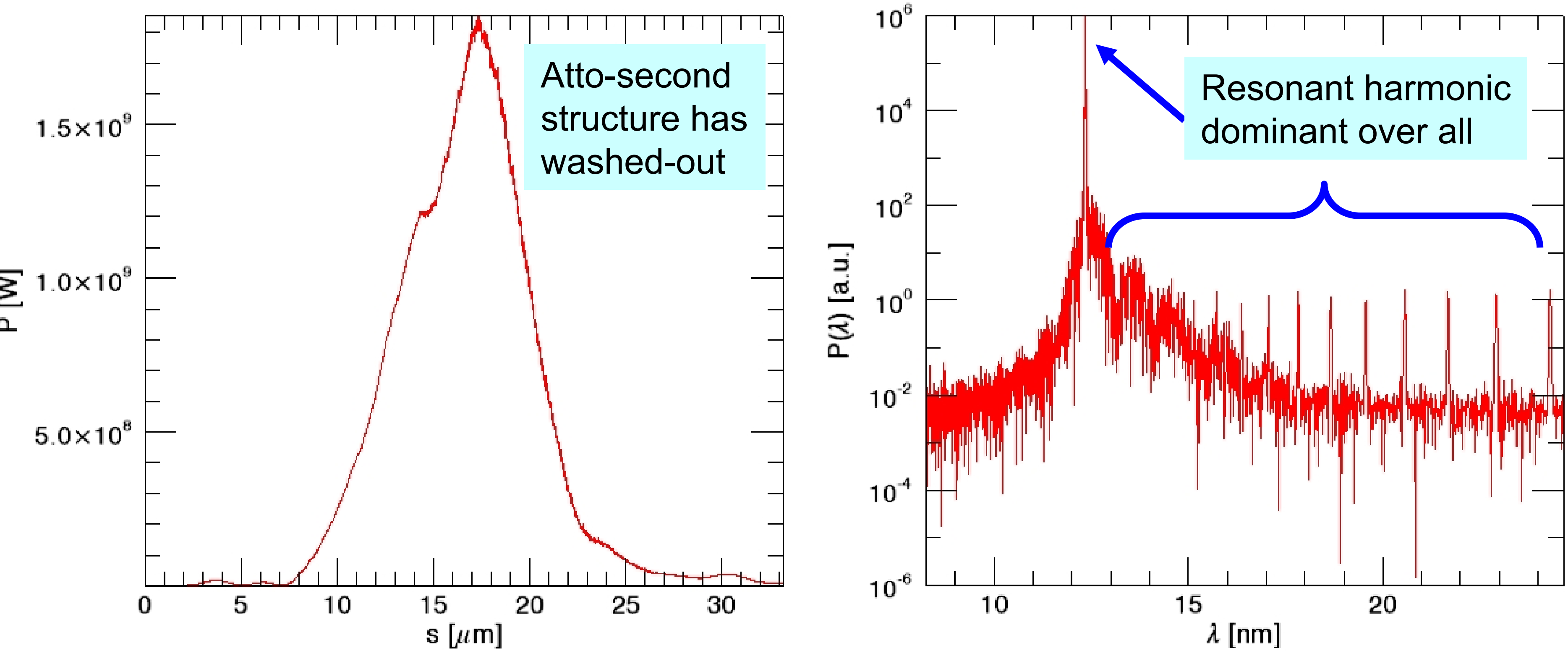




HHG seeded field at z~16 m

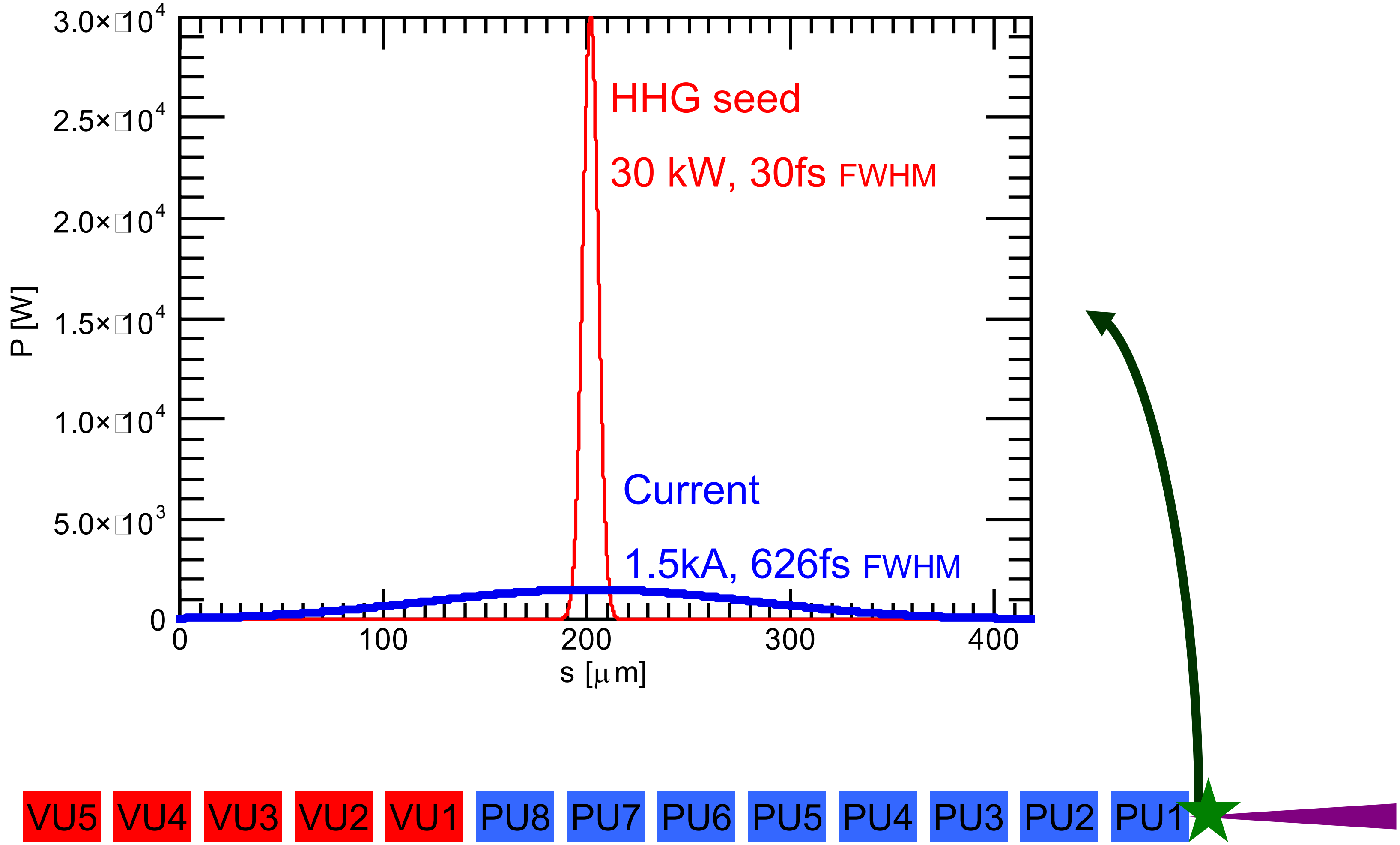
Genesis simulation



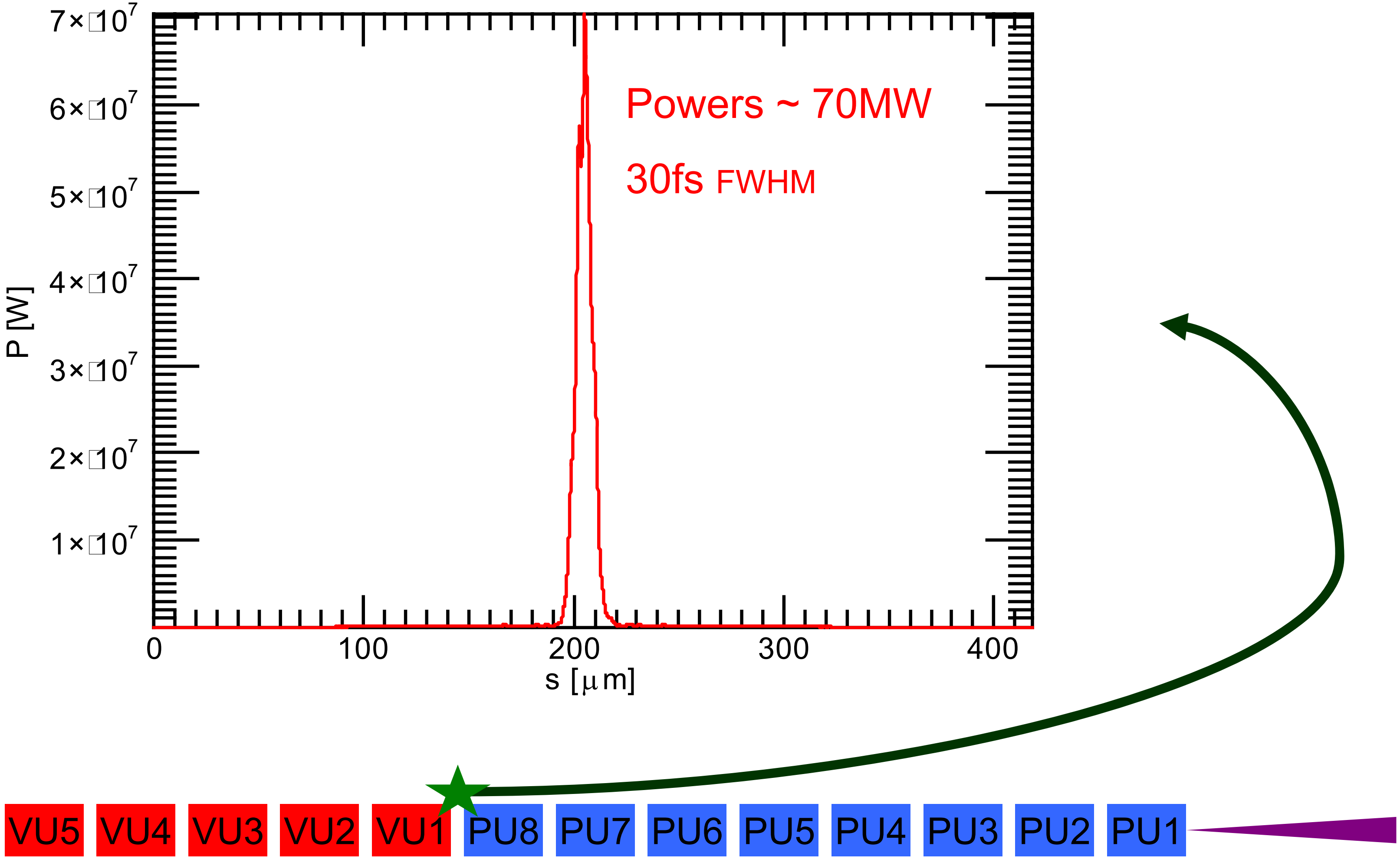
HHG seeded field at saturation z~32 m

Simulations of XUV-FEL conceptual design XUV lasing - Pulses @ 100eV

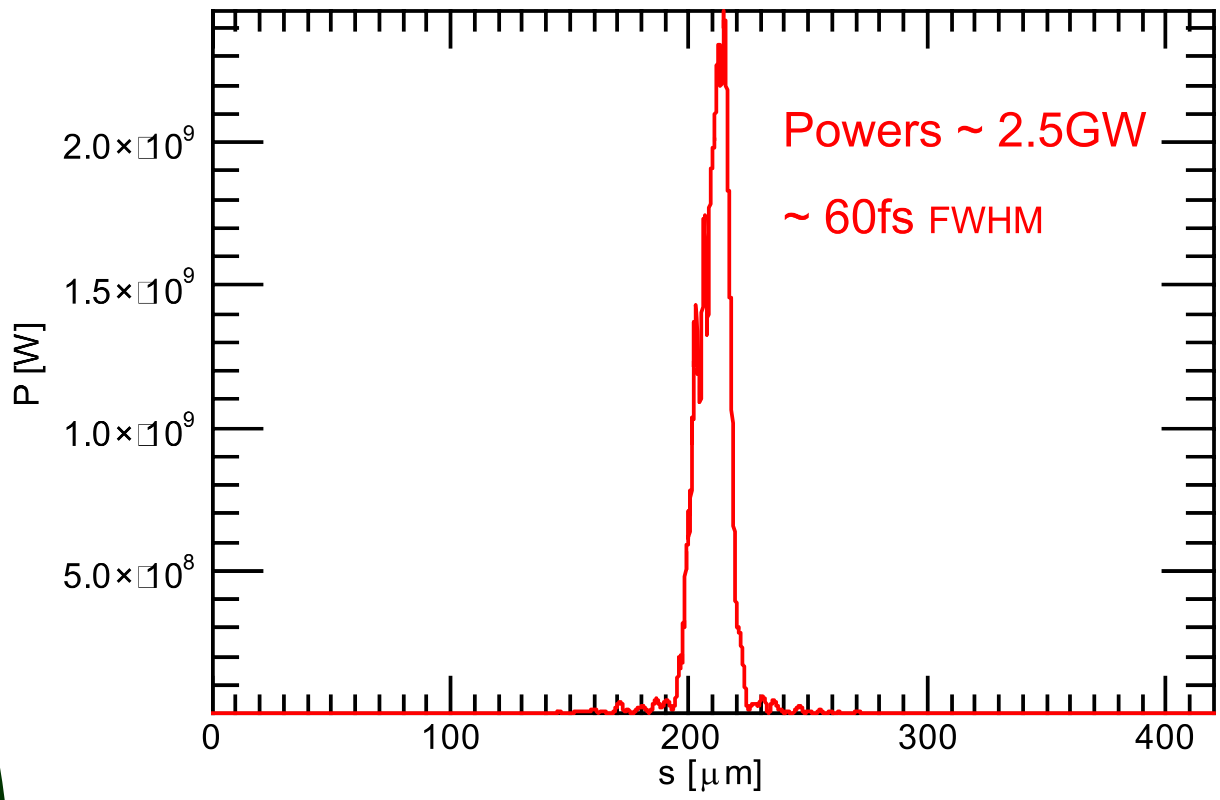
Planar undulator start PU1

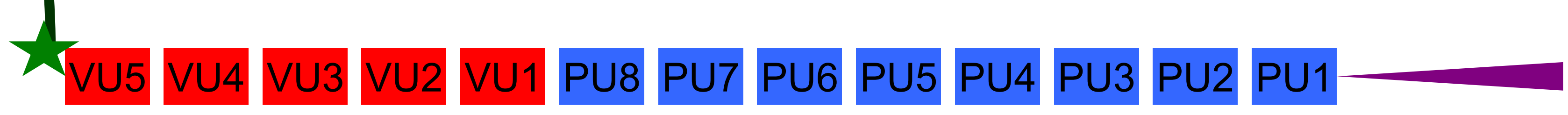


Planar undulator end PU8

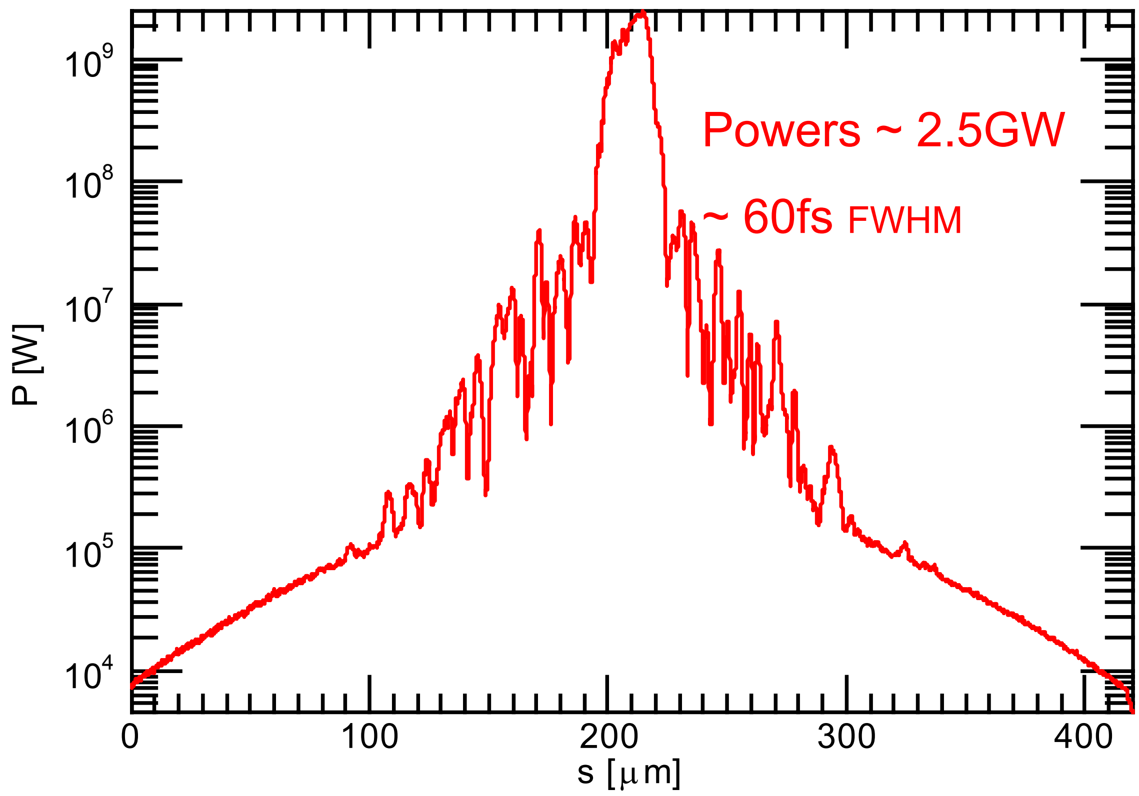


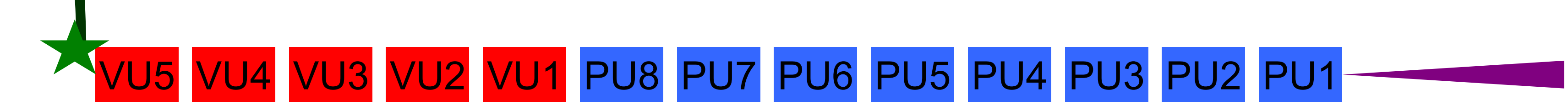
Helical undulator end VU5



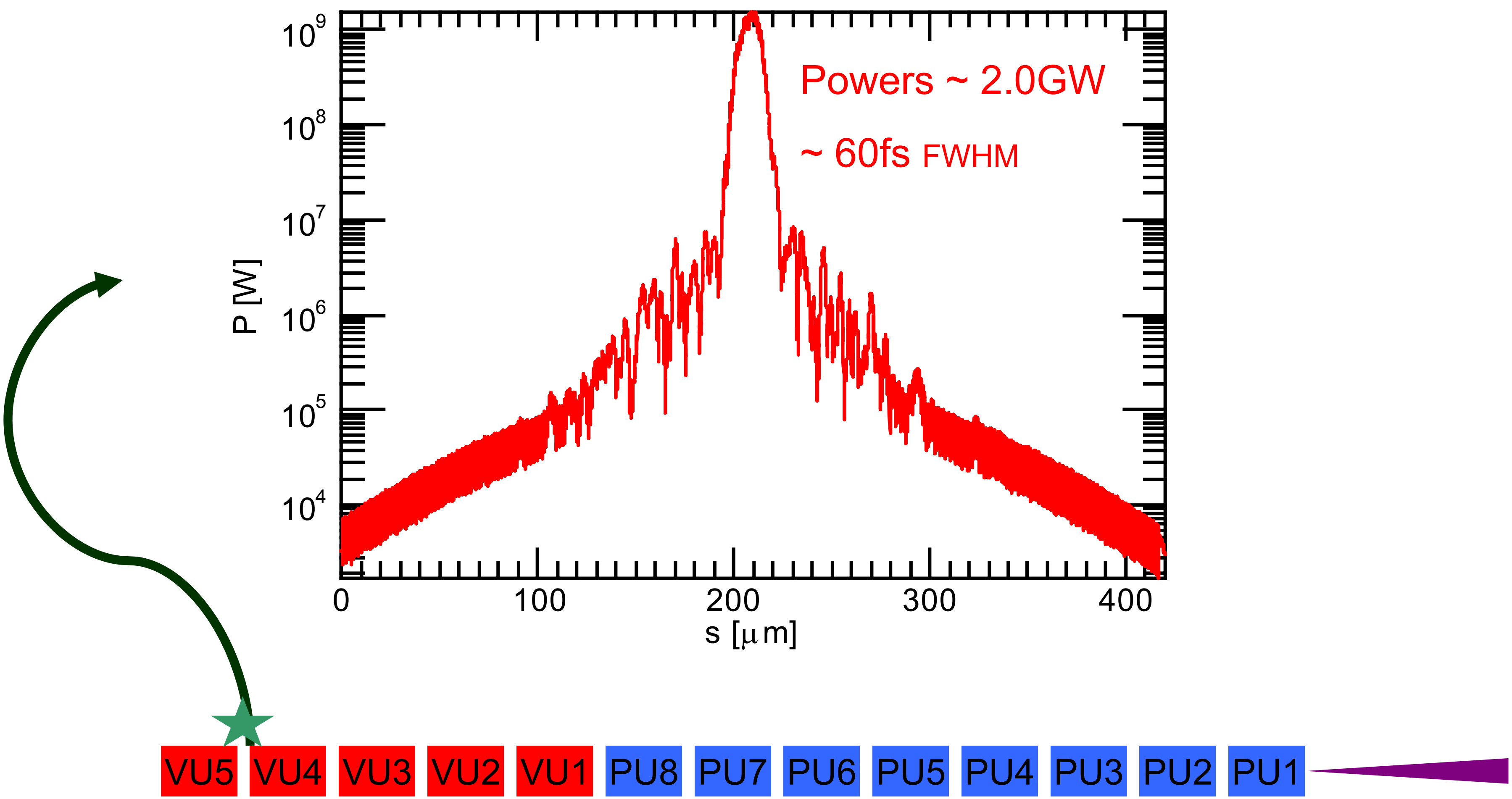


Helical undulator end VU5

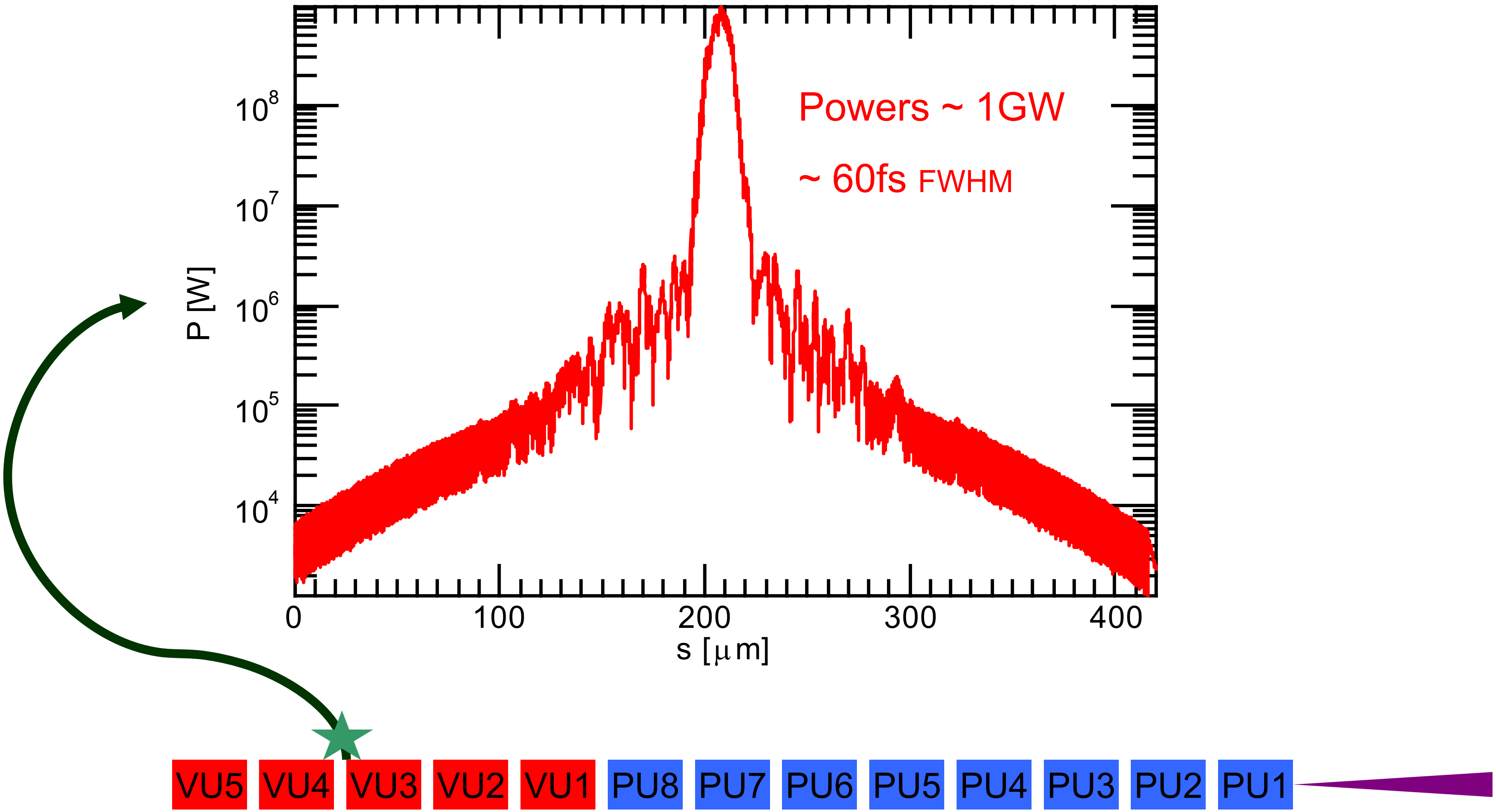




Helical undulator end VU4

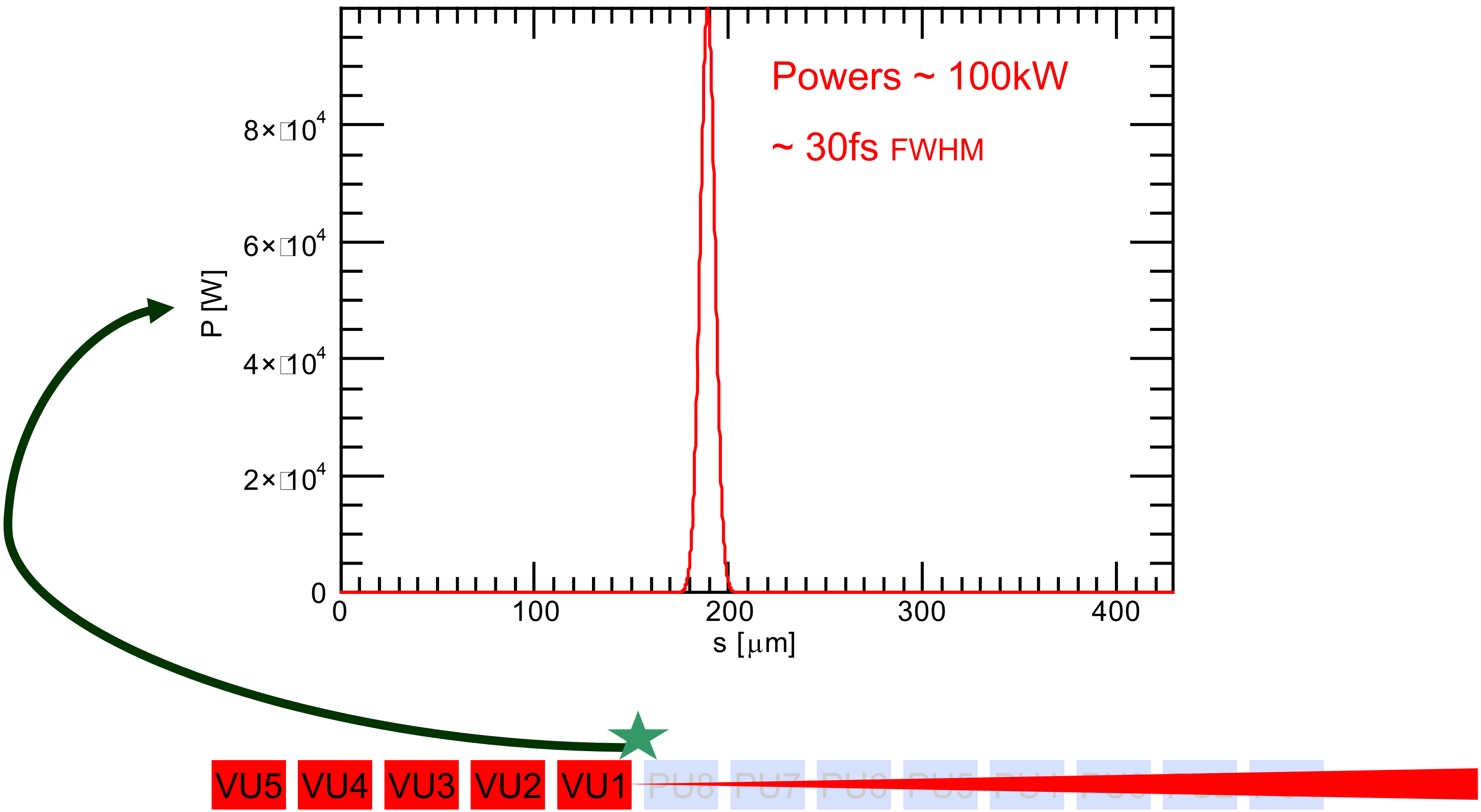


Helical undulator end VU3

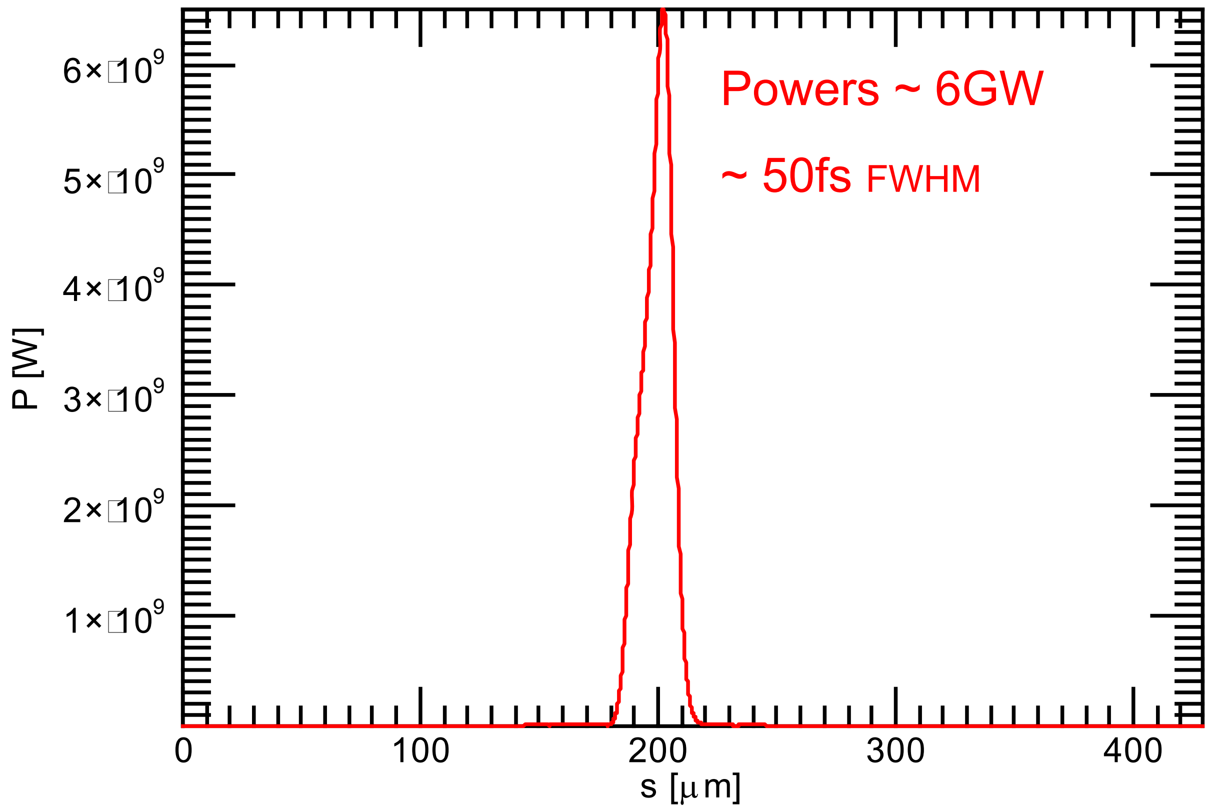


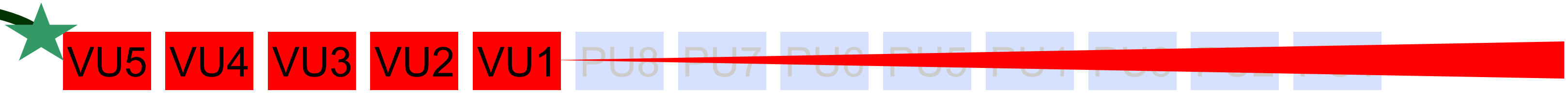
Simulations of XUV-FEL conceptual design XUV lasing - Pulses @ 10eV

Helical undulator start VU1

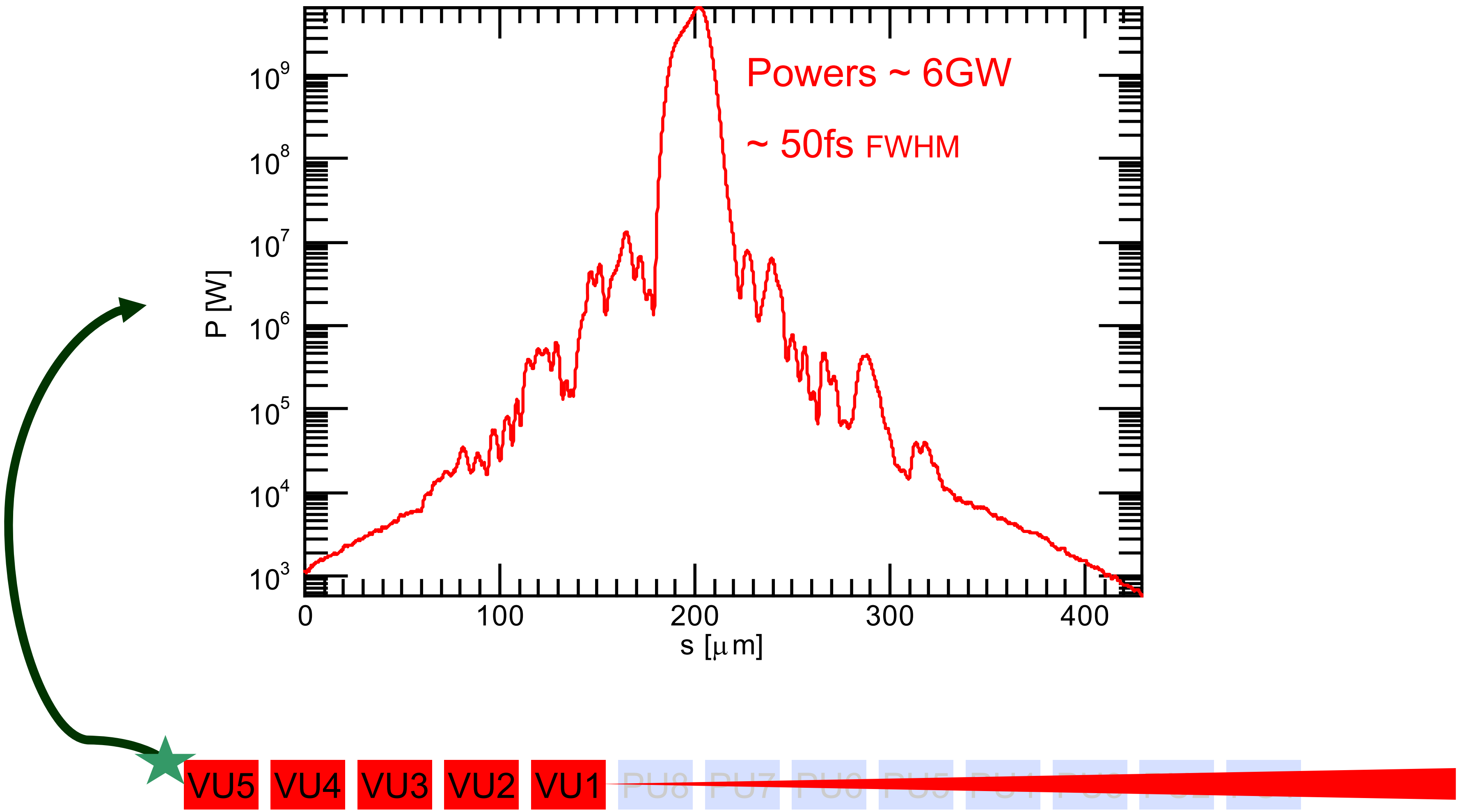


Helical undulator end VU5

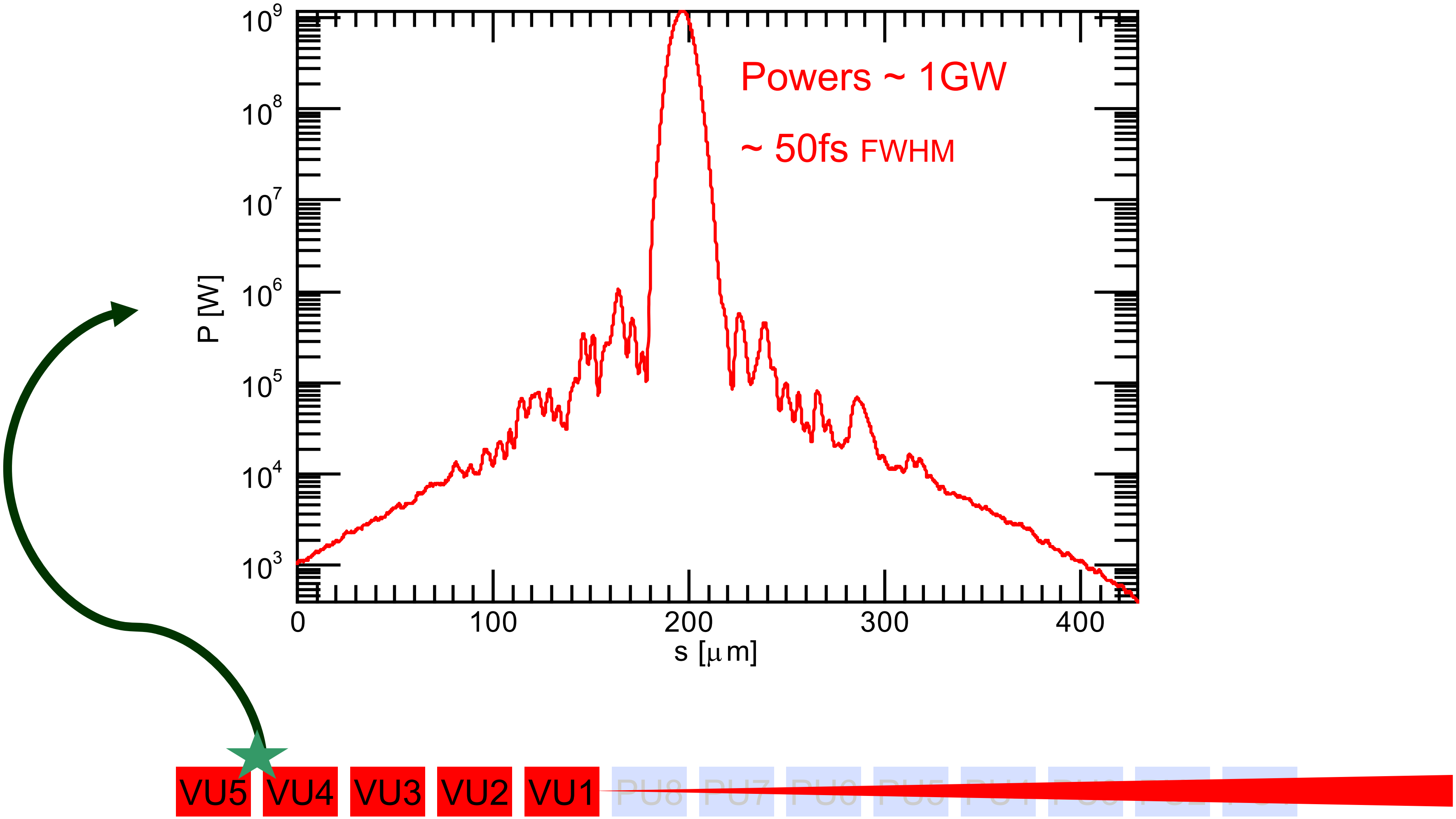




Helical undulator end VU5



Helical undulator end VU4



Further design work for XUV-FEL

- "Further design" – Technical Design Report ~end 2007
- Keep up-to-date with HHG development – rapidly changing
- Synchronism issues are critical*: keep timing offsets < 100 fs
- Need to simulate with more realistic electron pulses – s2e
- Re-assess and optimise design

*D. Dunning et al., *First Tolerance Studies for the 4GLS FELSources*, *TUPPH057*