HGHG Schemes for Short Wavelengths

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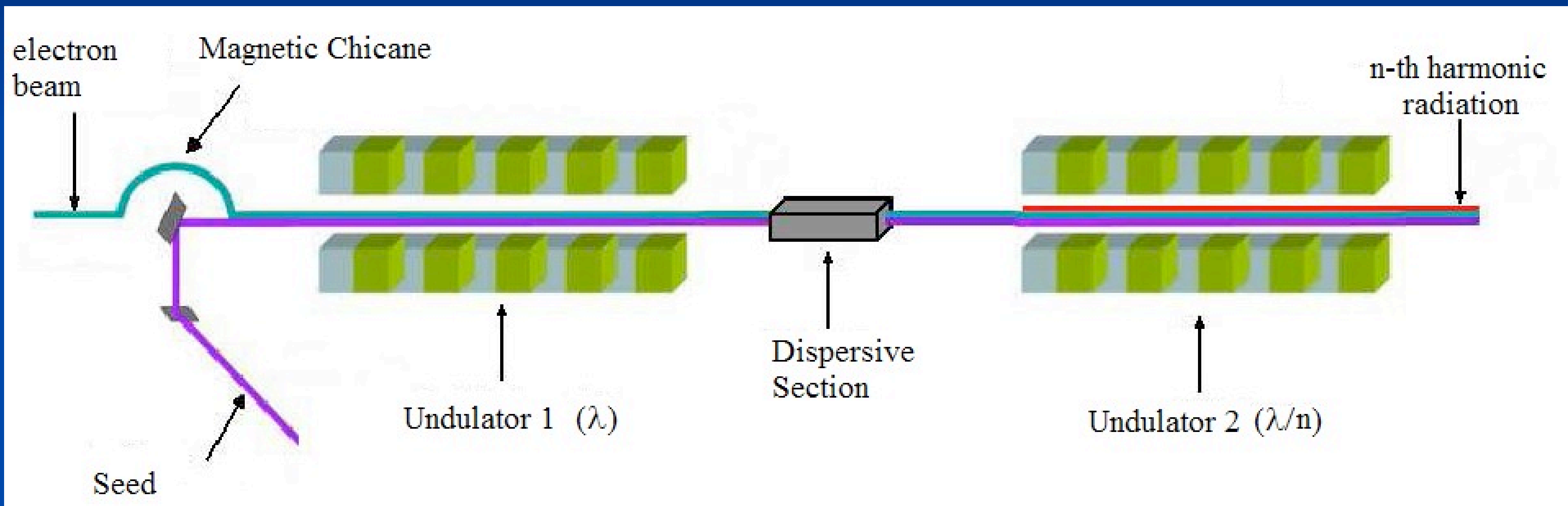
-Preliminary design of a single stage HGHG scheme for SPARX

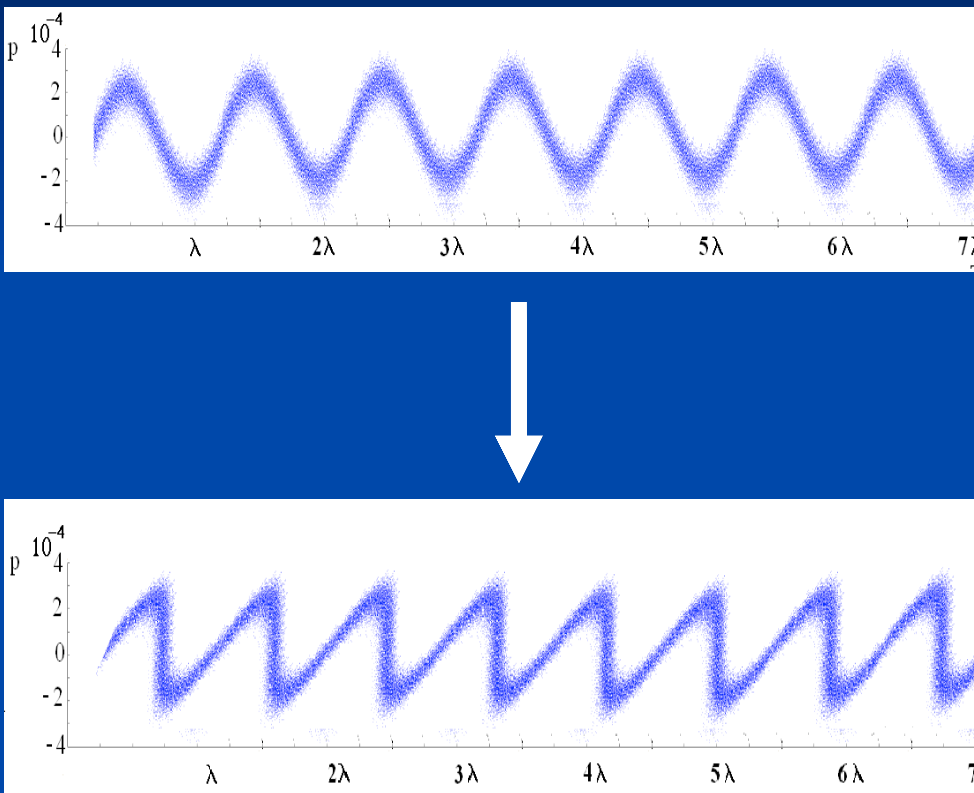
- Possible improvements

- Conclusions

HGHG: High Gain Harmonic Generation



The Dispersive Section



$$b_n = J_n(n\Delta p \frac{d\theta}{dp}) exp(-1/2(n\sigma_p \frac{d\theta}{dp})^2)$$

$d\theta/dp_{opt} = 1 / \Delta p$

$$b_{n,opt} \simeq max[J_n] exp(-1/2(n\frac{\sigma_p}{\Delta p})^2)$$

To have significant harmonic bunching

$\Delta p \sim n\, \sigma_p$

R. Bonifacio, R. Corsini, P. Pierini *Theory of the High Gain Optical Klystron* 1992 Phys. Rev. A 45, 4091.

Energy Spread Effects

In order to have significant bunching on

the n-th harmonic:

$$\Delta p \sim n\,\sigma_p$$

Efficient FEL process in the radiator if:

$$\Delta p << \rho$$

Thus:

$$\sigma_p << \rho/n$$

Shot Noise Effects

-Modulator

$$P_{seed} >> P_{sh} = \frac{3^{3/4} 4\pi \rho_{mod}^2 W_b}{N_\lambda \sqrt{\pi \bar{z}_{mod}}}$$

FEL process driven by both external seed and shot-noise

-Radiator

$$|b_{0,n,c}|^2 >> |b_{sh}|^2 = \frac{3^{3/4} 4\pi \rho_{rad}}{N_{\lambda/n} \sqrt{\pi \bar{z}_{rad}^{sat}}}$$

FEL process driven by both coherent harmonic bunching and shot-noise

Design Guidelines

-Choose a sufficiently high seed power to overcome shot noise effects in the modulator

-Choose a sufficiently high harmonic bunching factor to overcome shot-noise effects in the radiator

-Use an acceptable energy modulation

-Design the modulator and the dispersive section to fulfill previous choices

Undulators

MODULATOR

- λ_r =13 nm
- λ_u = 5.4 cm
- K = 4.3358

n=5

RADIATOR

- λ_r =2.6 nm
- λ_u= 2.7 cm
- K = 2.5124

Electron Beam (SPARX case)

E=2.3 GeV

I=2.4 kA

ε =1 mm mrad

σ_p= 10^{-4}

$\sigma_x = \sigma_y$ =4.2 10^{-5} m

Method

- 3-D Time Dependent Simulations with GENESIS 1.3

- Undesired effects evaluated individually

-Joint effects evaluated on the final configuration

Temporal coherence properties in the modulator

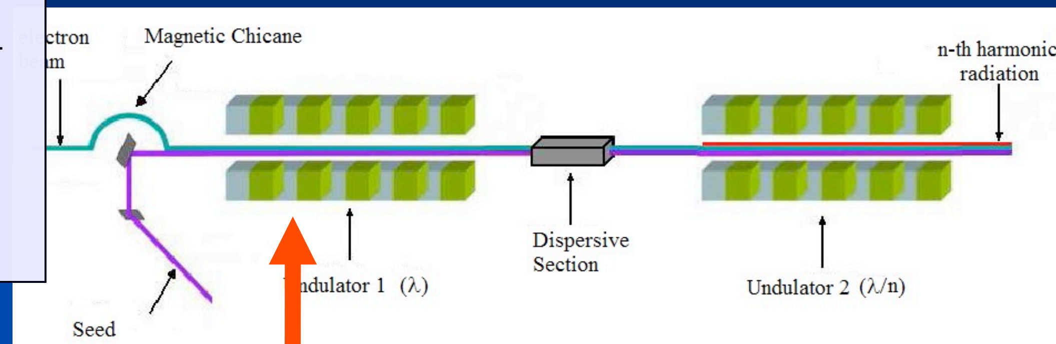
$$P_{seed} > 30\ \text{kW}$$

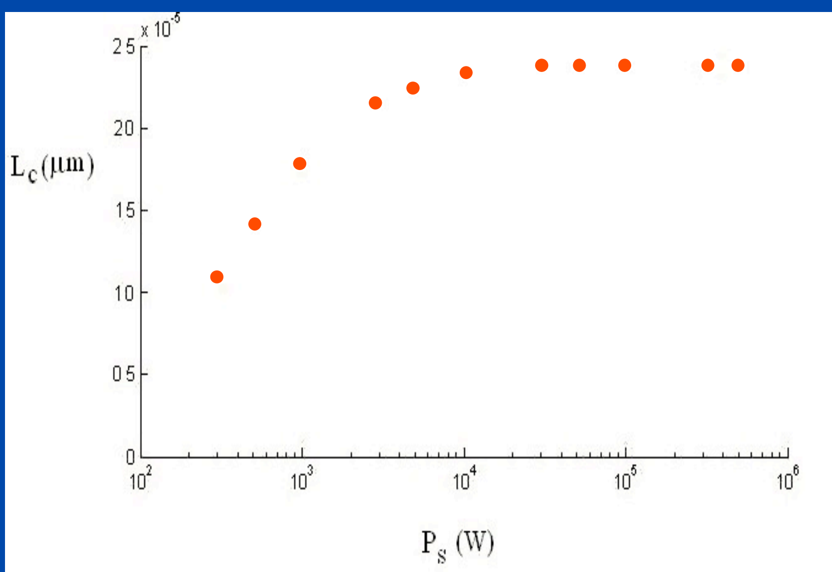
(first order)

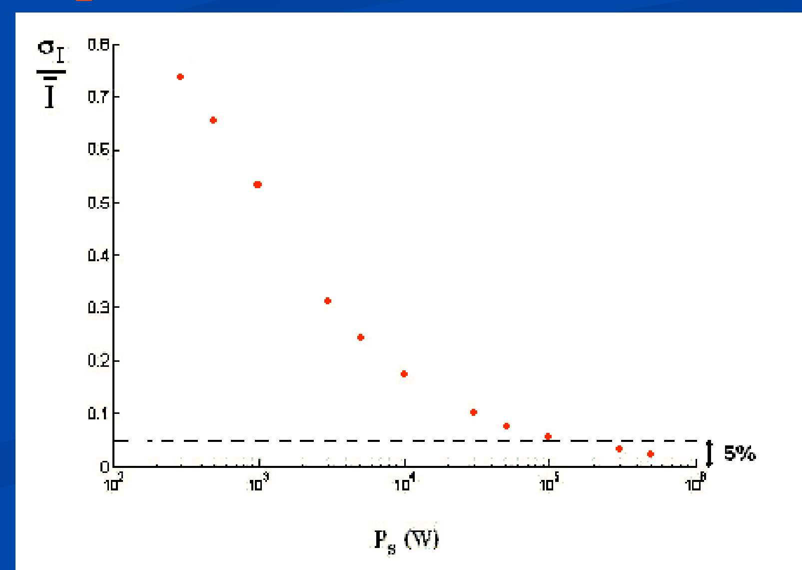
$$P_{seed} > 300\ \text{kW}$$

(second order)

electron and seed beams



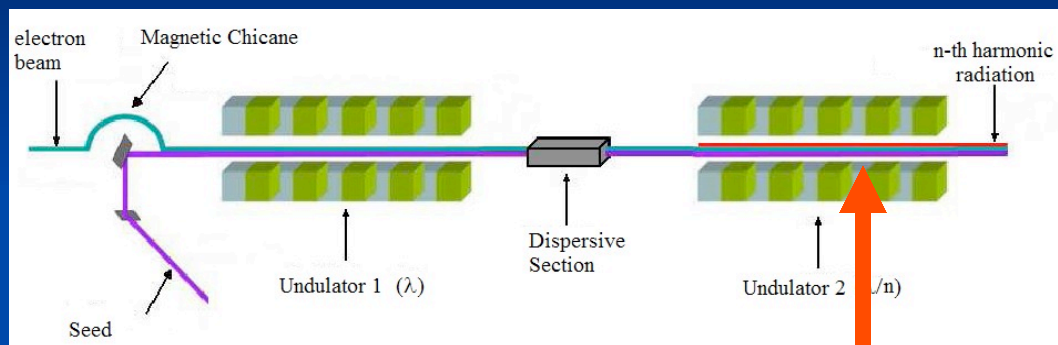


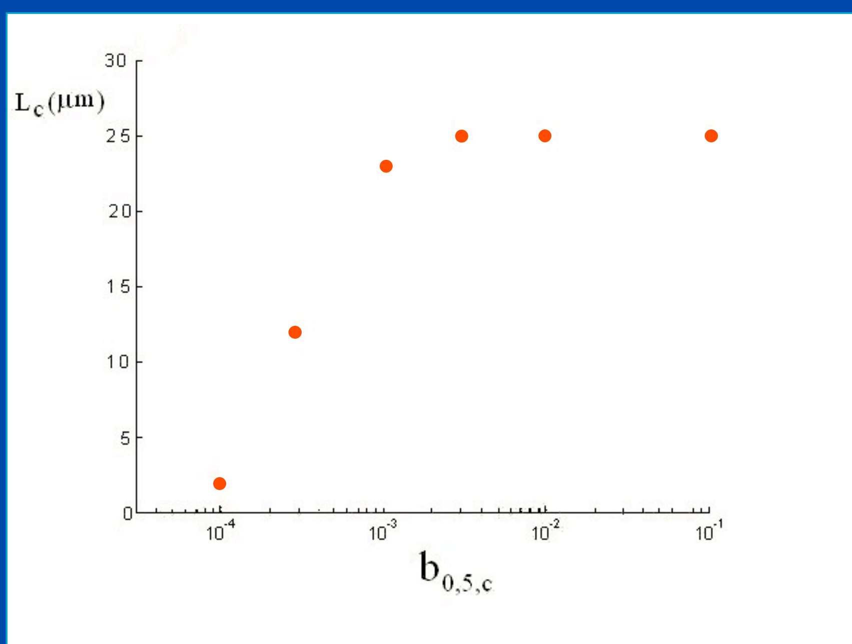


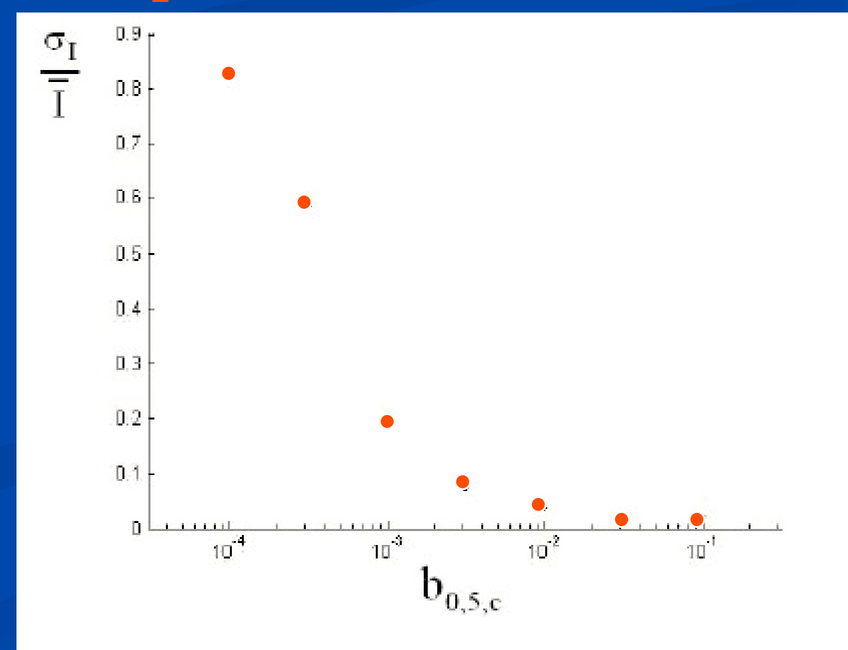
Temporal coherence properties in the radiator (“fresh beam”)

$b_5 > 0.03$

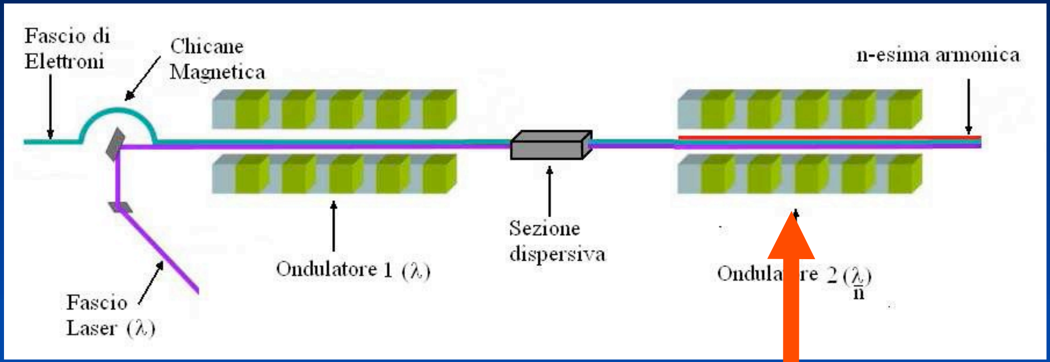
(first and second order temporal coherence)

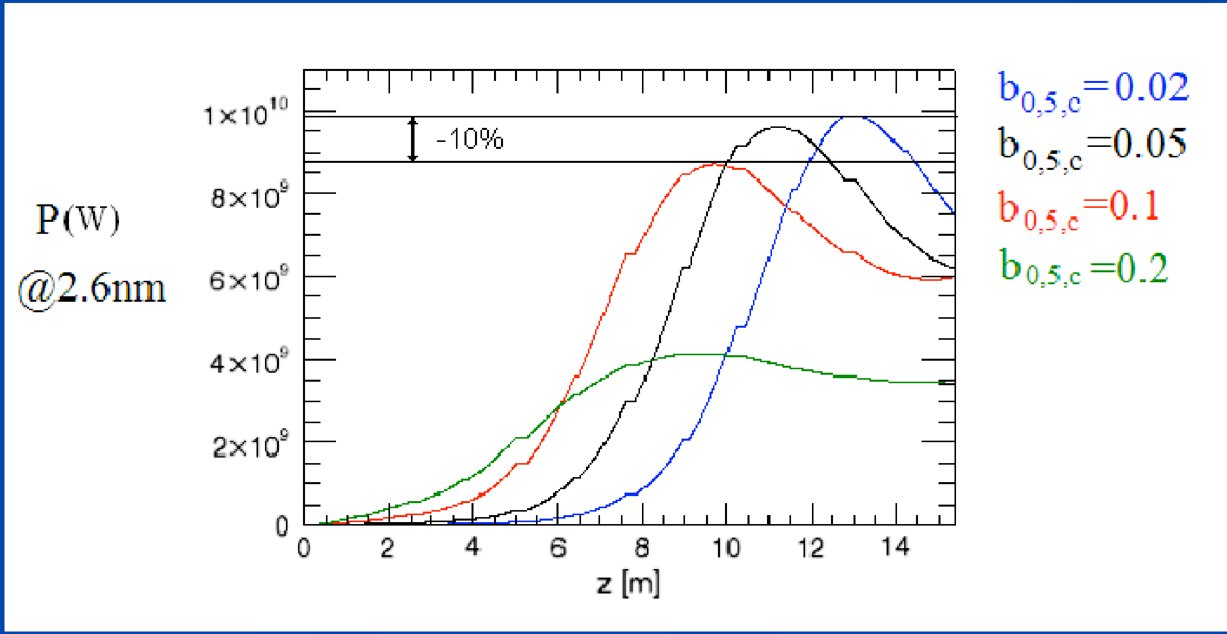






Energy Spread effects

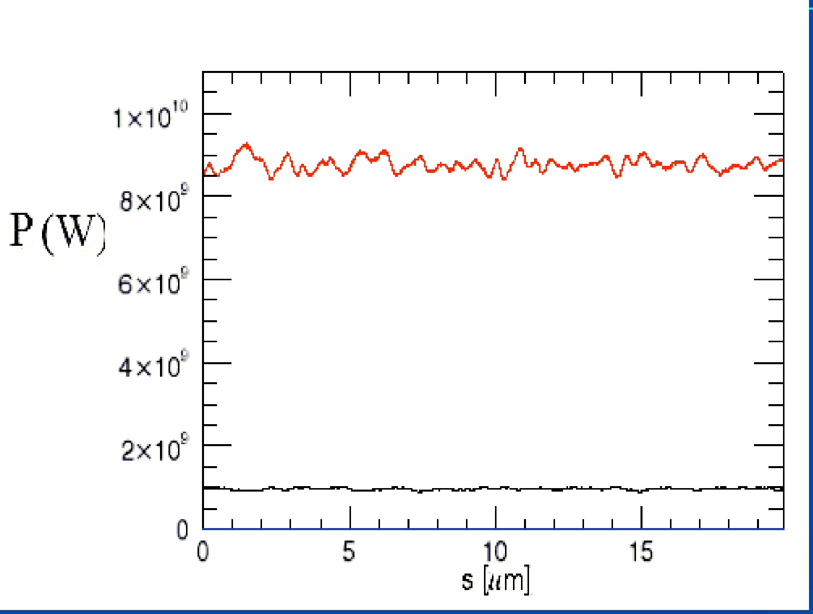




Time Dependent Simulations

2 cases

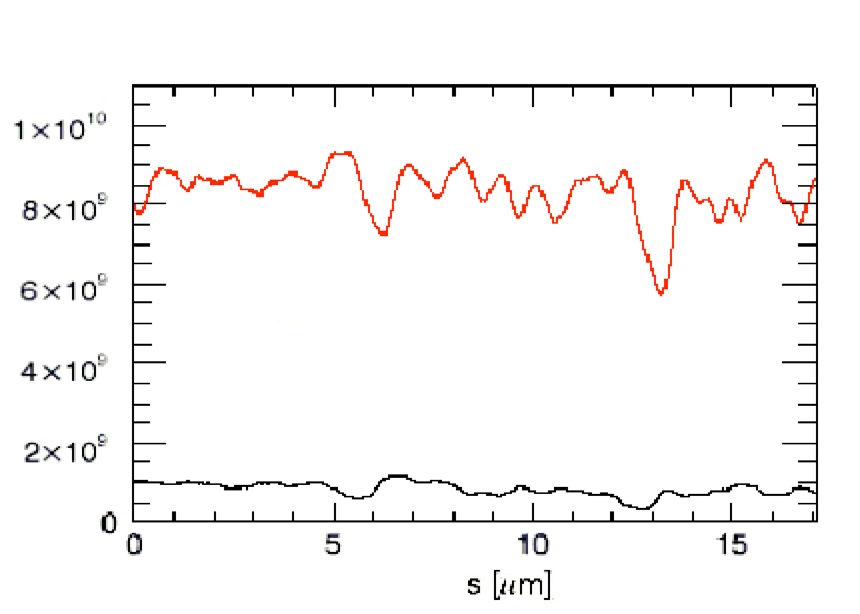
Ps = 300 kW, b_5=0.1	Ps = 30 kW, b_5=0.1
Lc=2/3 Lb, σ_I /I=1.9%	Lc=0.9 * 2/3 Lb, σ_I /I=8.8%



z= 9.5m (saturation)

z=5m

z=0



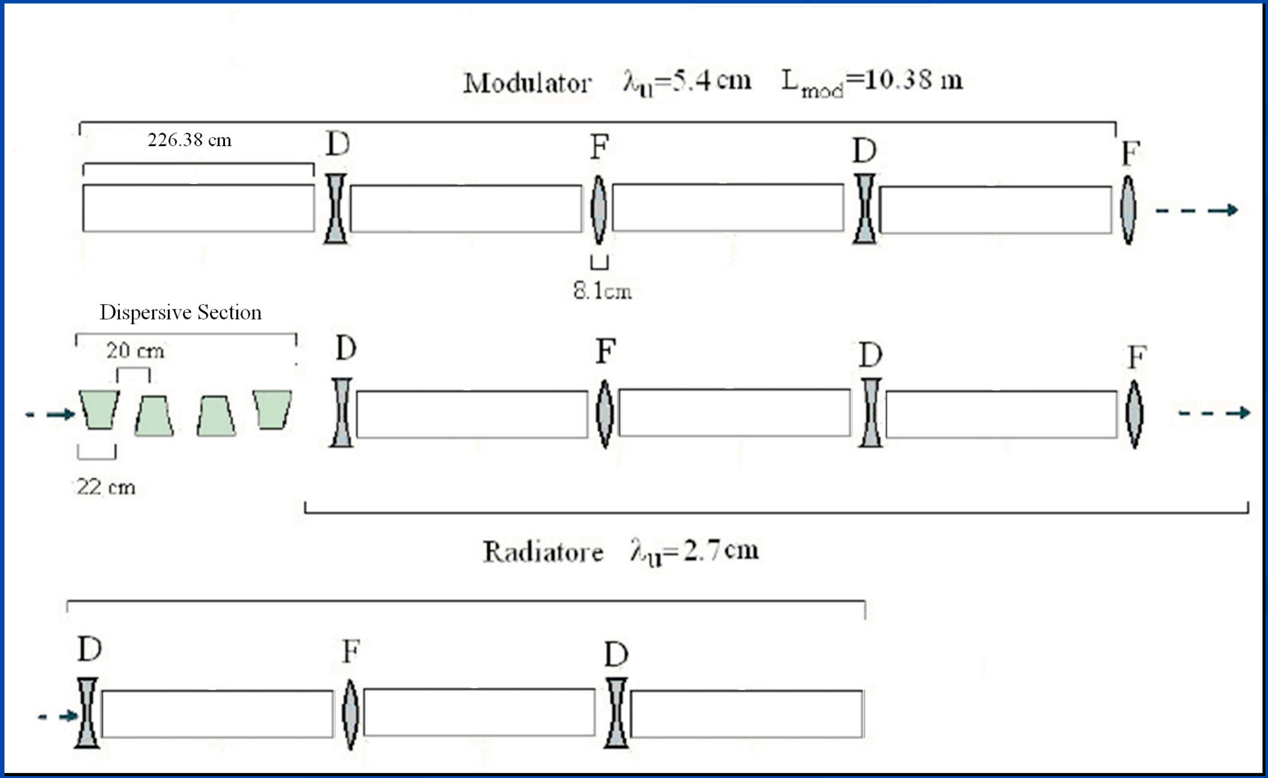
Possible HGHG scheme for SPARX

Ps_{PEAK}=50kW

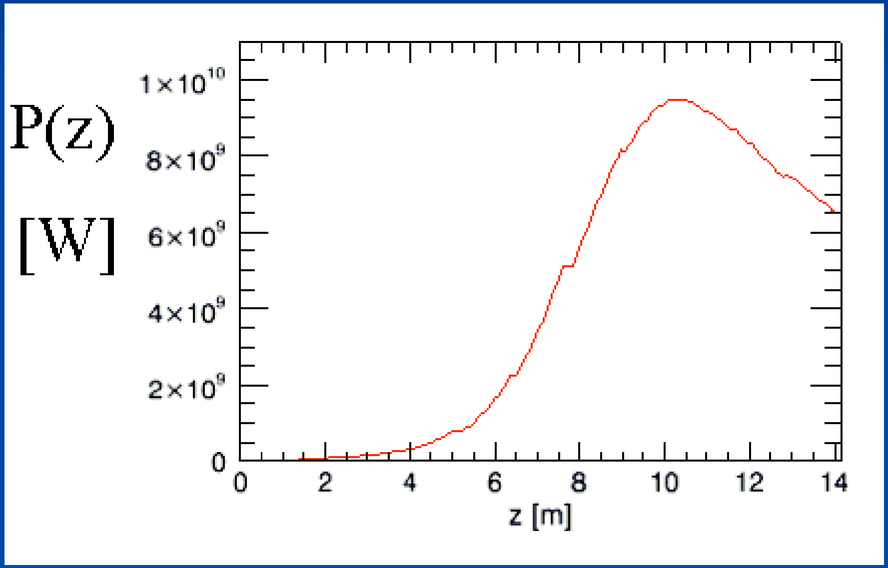
b_{5IN}=0.08

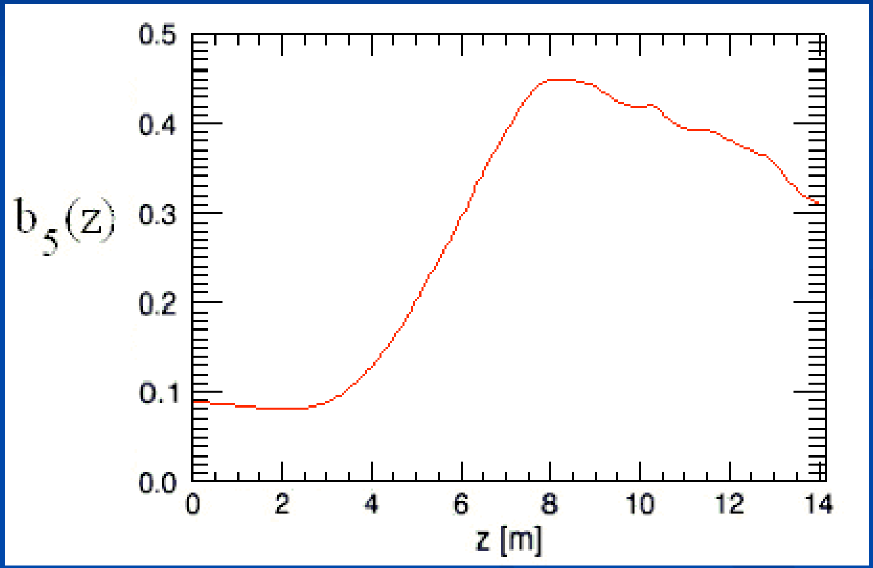
T_{FWHM}=70fs

(Feasible with HHG)



Peak Power and Bunching Along the Radiator (2.6 nm)



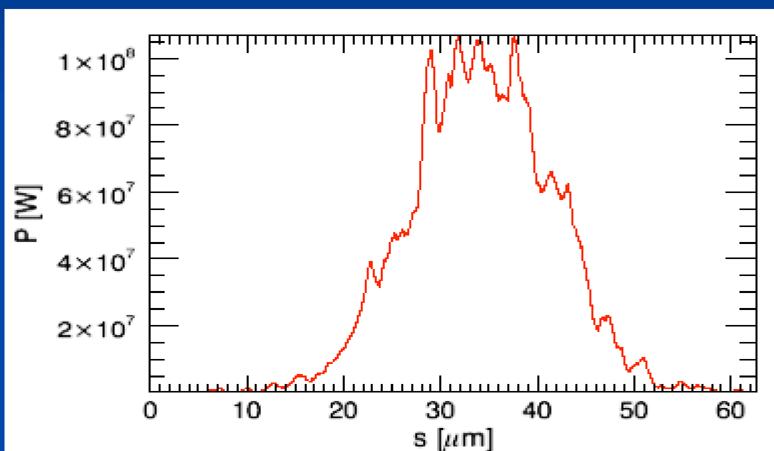


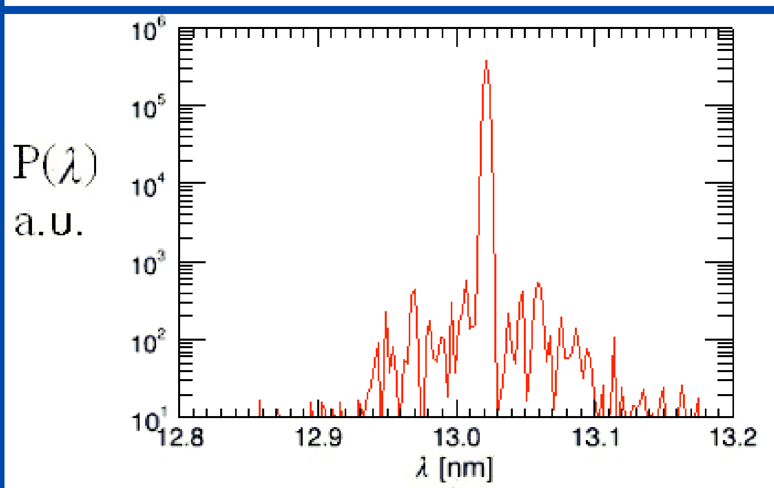
Saturation in 10 m

Gaussian Beams
(both radiation and electrons)

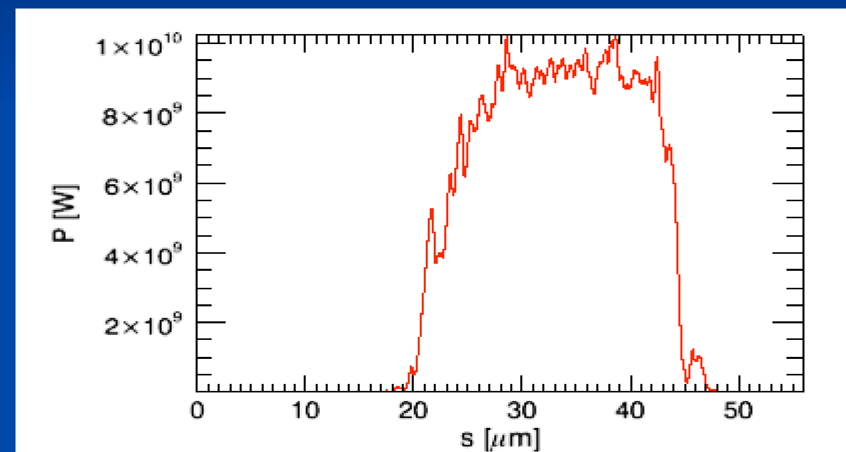
50kW Seed Peak Power (realistic with HHG in gases)

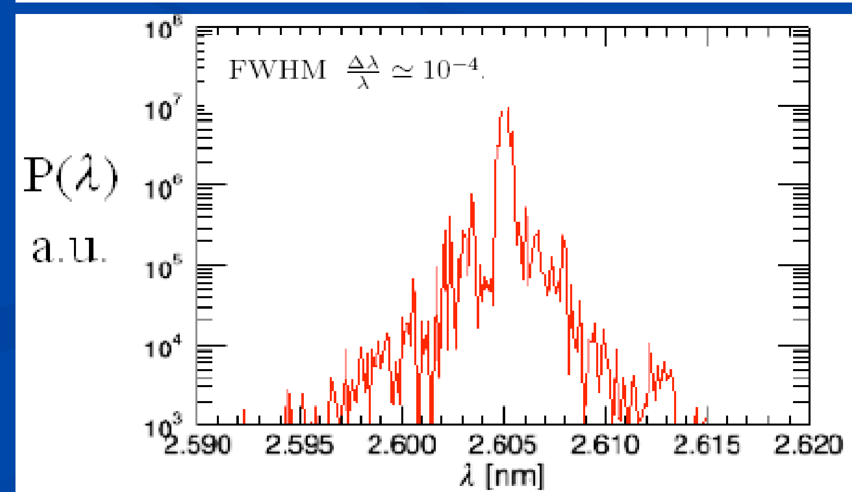
1 st Harmonic





5 th Harmonic (saturation)





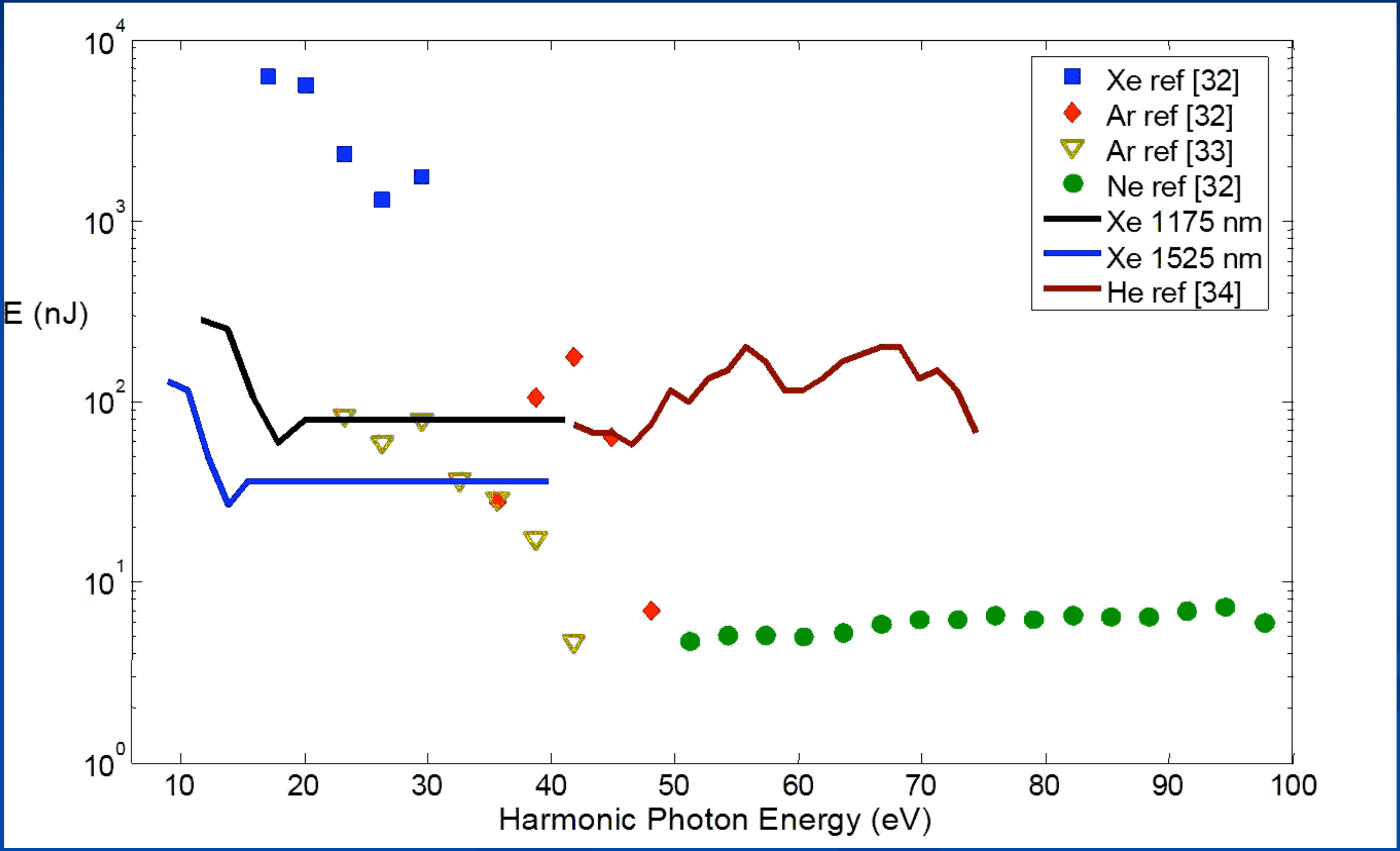
How Can We Do Better With a Single Stage HGHG?

Shot noise is the main issue in HGHG schemes at X-UV wavelengths:

-Alternative seeding sources

-Decreasing the equivalent shot-noise power

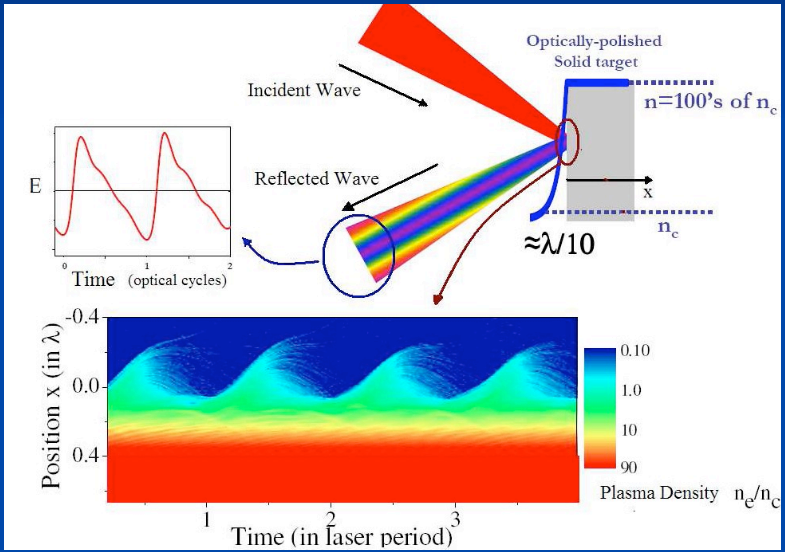
HHG in gases

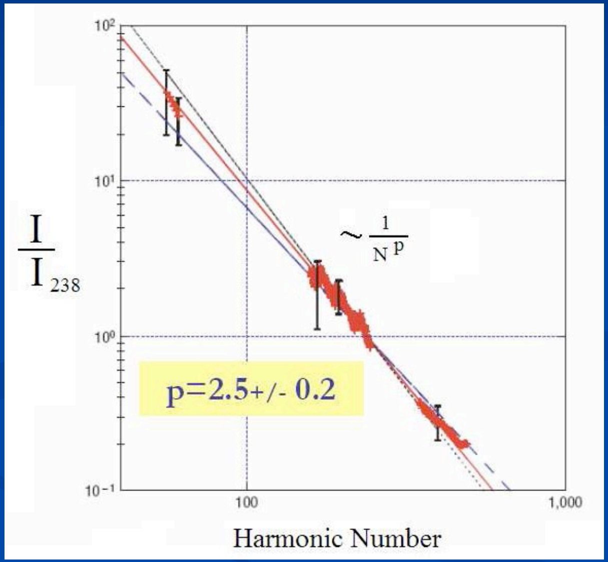


10^4
10^3
10^2
10^1
10^0
E (nJ)
10
20
30
40
50
60
70
80
90
100
Harmonic Photon Energy (eV)
Xe ref [32]
Ar ref [32]
Ar ref [33]
Ne ref [32]
Xe 1175 nm
Xe 1525 nm
He ref [34]

Alternative Seeding Sources: Relativistic Oscillating Mirror

Thaury et al., Nature Physics 3, p. 424 (2007)





B. Dromey et al, Nature Physics 2, p. 456 (2006)

0.2 mJ @ 17 nm
0,07 mJ @ 4 nm
(t=600 fs)

η~10 e−6±1 (0.07-0.7 mJ) and 3×10e −5±1 (0.2-20 mJ) at 4 and 17nm respectively

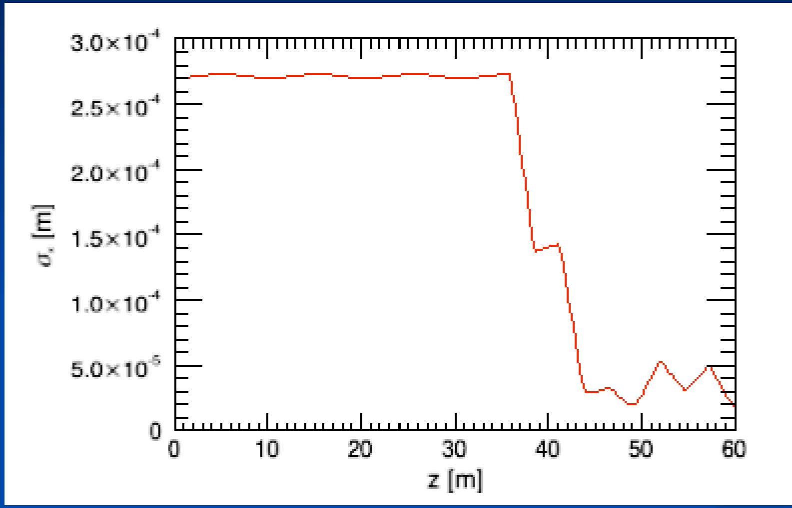
Low Noise Seeding

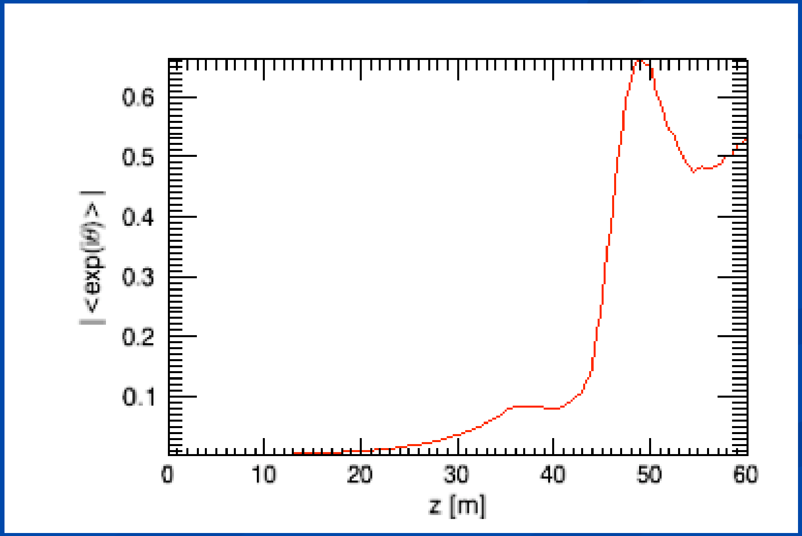
$$P_{sh} = \frac{3^{3/4} 4\pi\rho^2 W_b}{N_\lambda \sqrt{\pi \bar{z}}}$$

$$\rho \propto \gamma_r^{-1} \sigma_e^{-1/3} I^{1/3} a_u^{2/3} \lambda_u^{2/3}$$

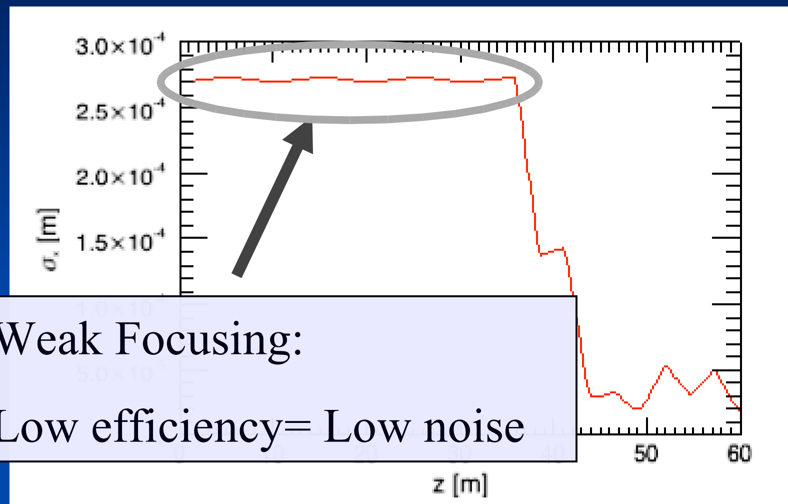
$$P_{sh} \propto \sigma_e^{-2/3}$$

Low Noise Seeding



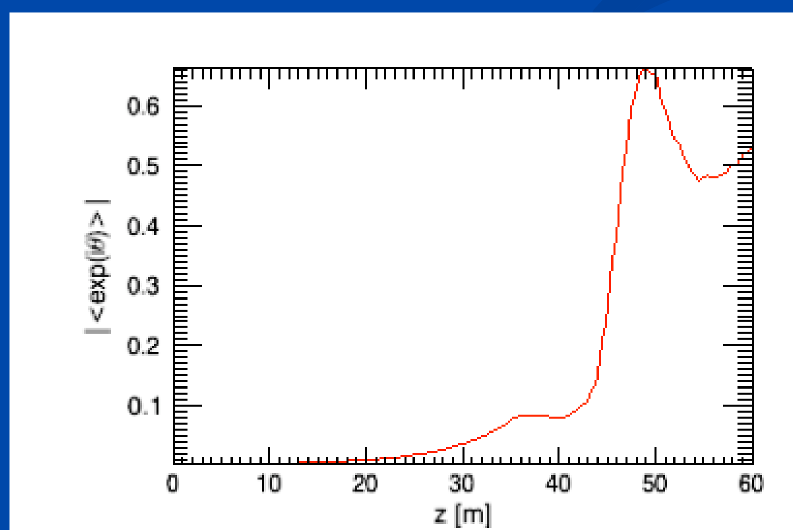


Low Noise Seeding



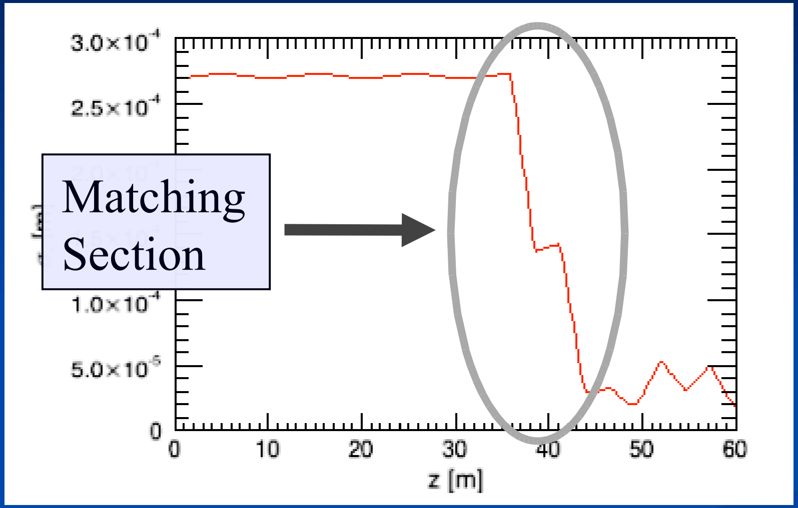
Weak Focusing:

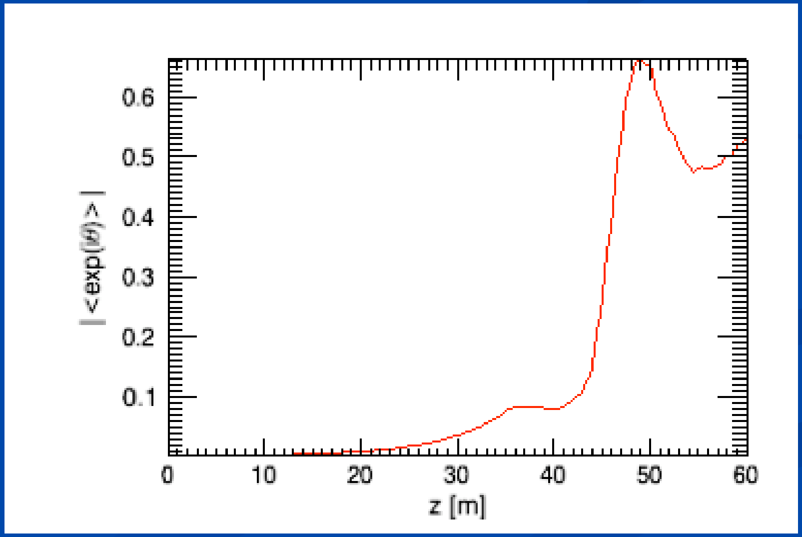
Low efficiency= Low noise



$$P_{sh} \propto \sigma_e^{-2/3}$$

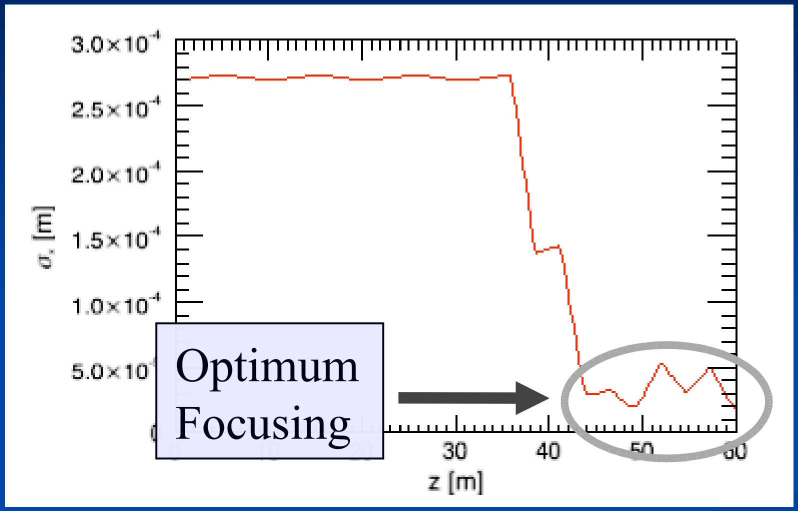
Low Noise Seeding

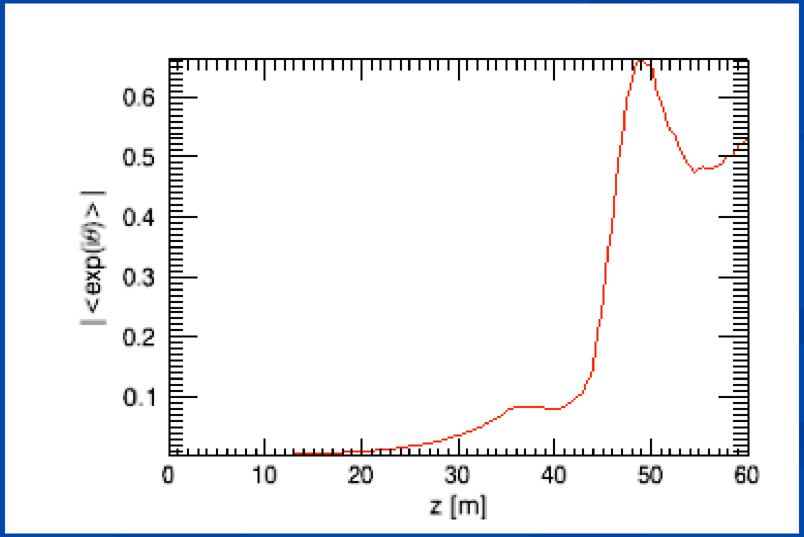




$$P_{sh} \propto \sigma_e^{-2/3}$$

Low Noise Seeding





$P_{sh} \propto \sigma_e^{-2/3}$

Low Noise Seeding

Suitable for:

-HGHG modulator

-Seeding at shorter wavelengths

Problems:

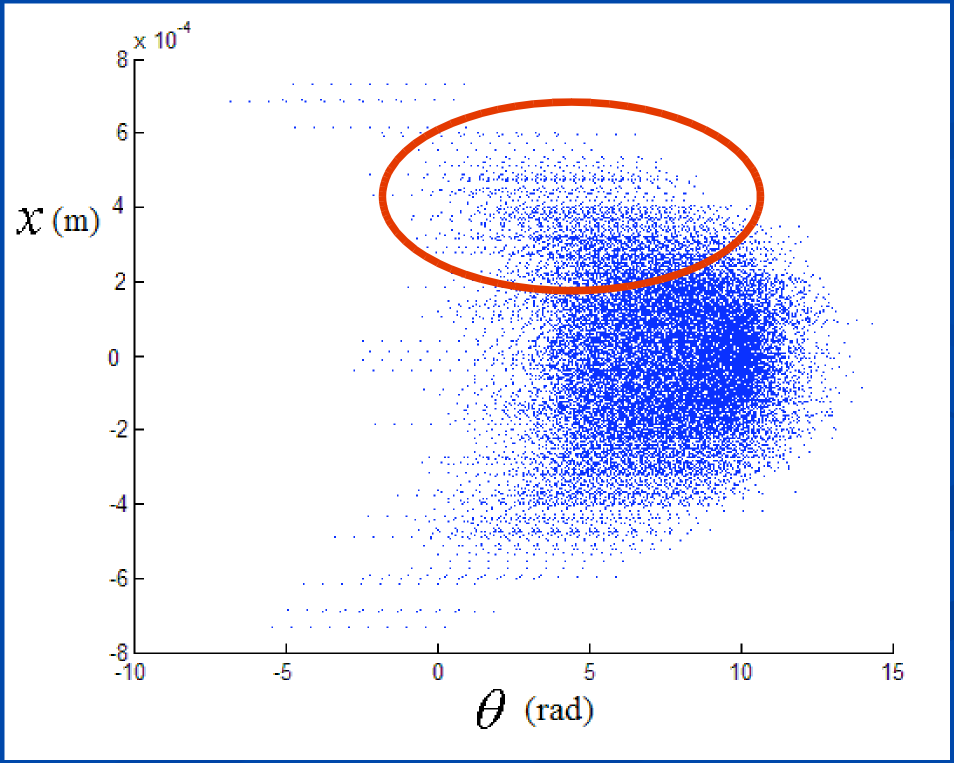
-Longer undulator! (costs, alignment...)

-Bunched beam transport issues

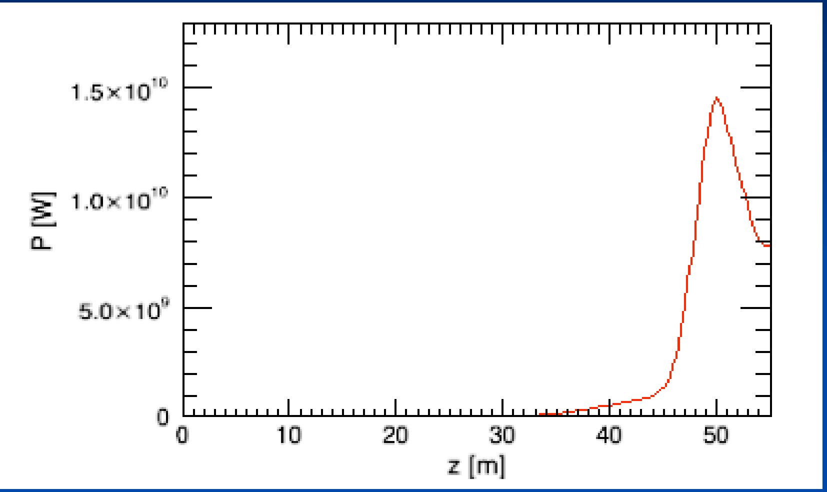
Low Noise Seeding

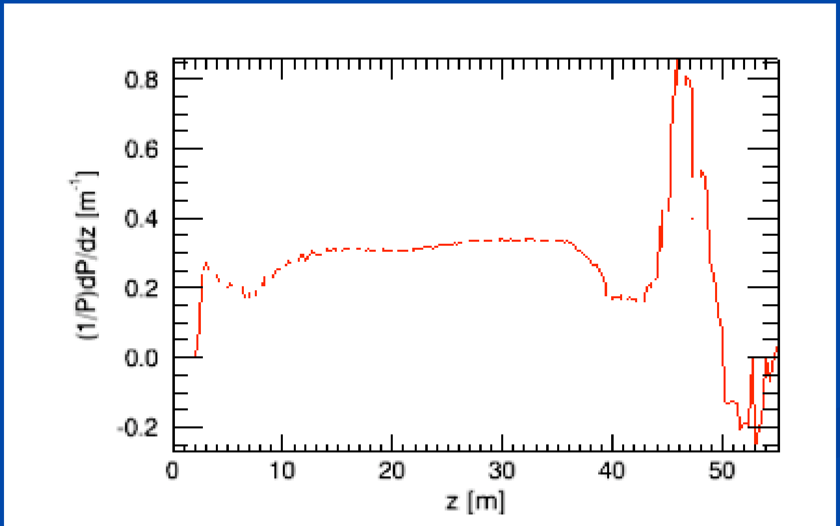
External particles get a stronger transverse kick in the matching section and slip backwards in phase:

bunching factor decreases!

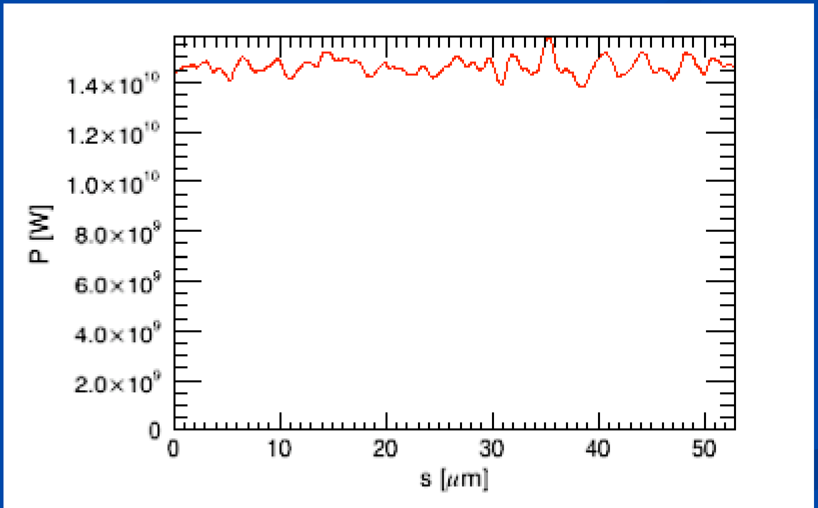


Low Noise Seeding
Example : 30kW seed





2% Intensity Fluctuations



Conclusions

- A method for the design of a single stage HGHG has been discussed
- Preliminary study on a possible HGHG scheme for SPARX has been carried out
-Studies on possible improvements are ongoing

Acknwledgments

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