laboratoire d'optique appliquée

Palaiseau - FRANCE

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An intense kHz and aberration-free two-colour high harmonic source for seeding FELs from EUV to soft X-ray range

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Thanks to Imagin Optics

Motivations for seeding with High order Harmonics (HH)

Goal: *femtosecond, high repetition rate, fully coherent FEL light at short wavelengths with high stability and high tuneability in a short scale facility*

=> Seeding with HH produced in gas

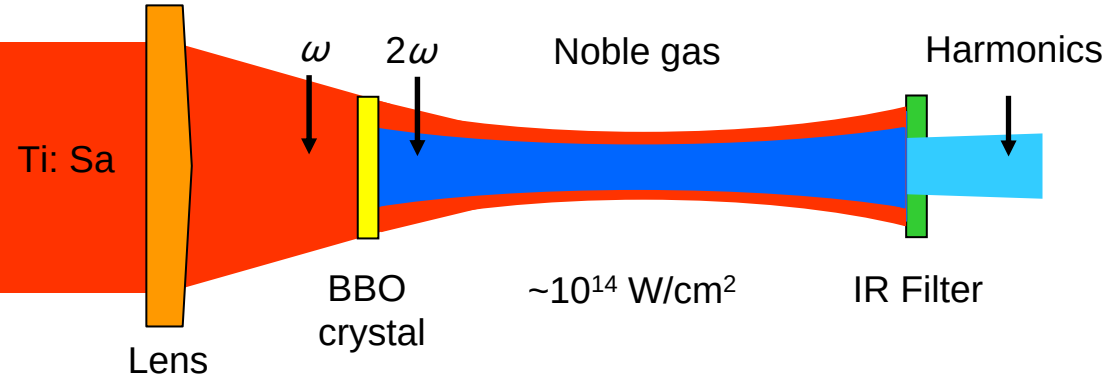
Harmonics properties

Already obtained	To be improved
-fs pulse duration -Full coherence -High repetition rate: kHz HH currently First MHz HH in xenon (J. Boullet et al. *optics letters*, 34, 1489 (2009))	-Intensity at short wavelengths: for instance: needed from 32 nm to 13 nm at sFLASH in 2010 -Tuneability (only odd HH): => need to considerably chirp the driving laser and/or change the gap of the undulator -Wavefront: diffraction limited beam (aberration-free) => need to drastically clip the amplified HH beam or use adaptive optics for HH -Stability of the shot to shot intensity

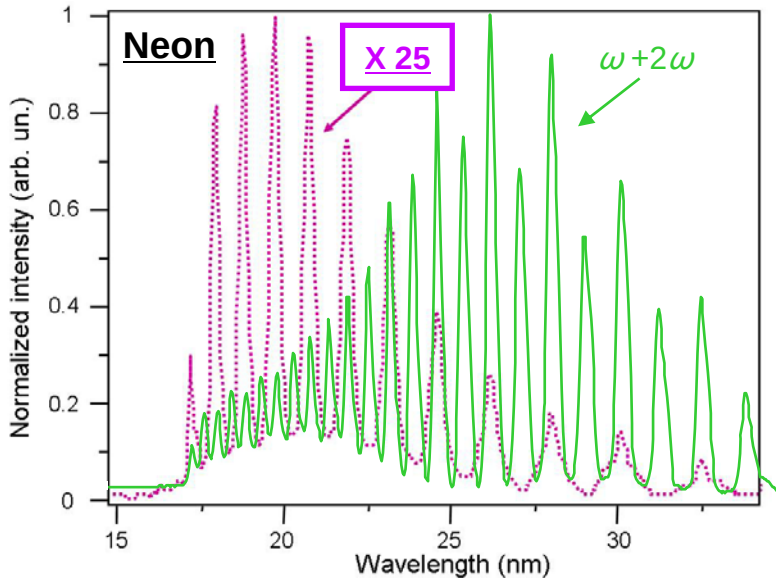
Keep the simplicity of the classical HH setup

High order harmonics generated with a two-colour field

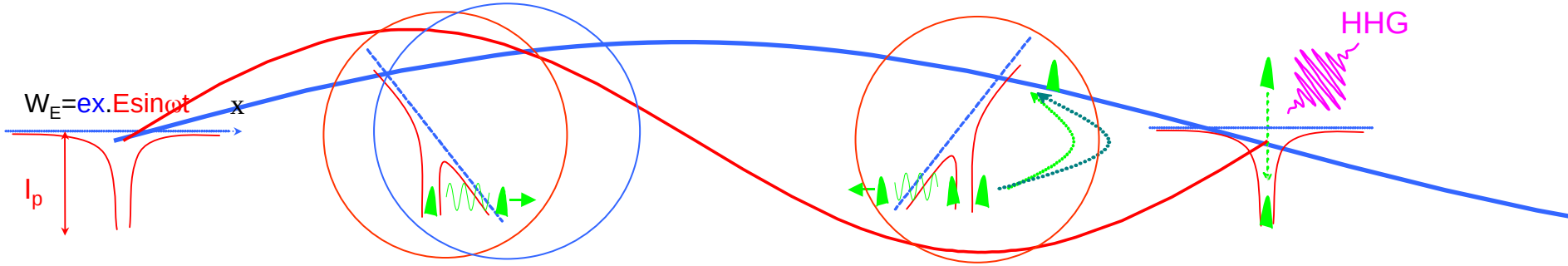
Theoretical and technical principles:



G. Lambert et al. to be published in New Journ. of Phys.



Semi-classical model in three steps:



Initial state
t~0

Tunnel ionization
t~T/4

Oscillation
in the laser field
t~3T/4

Radiating recombination
t~T

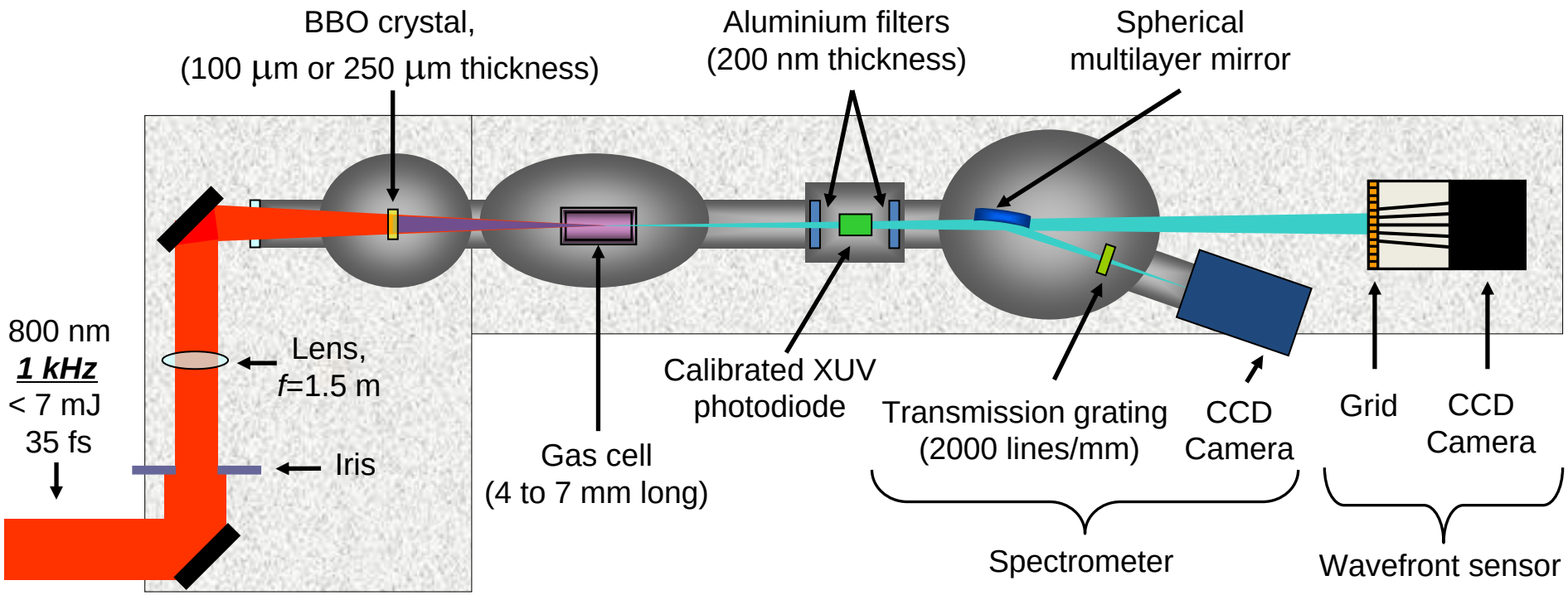
-double harmonic content
even types:
2x(2n+1) from 2ω
2x(2n) from the mixing

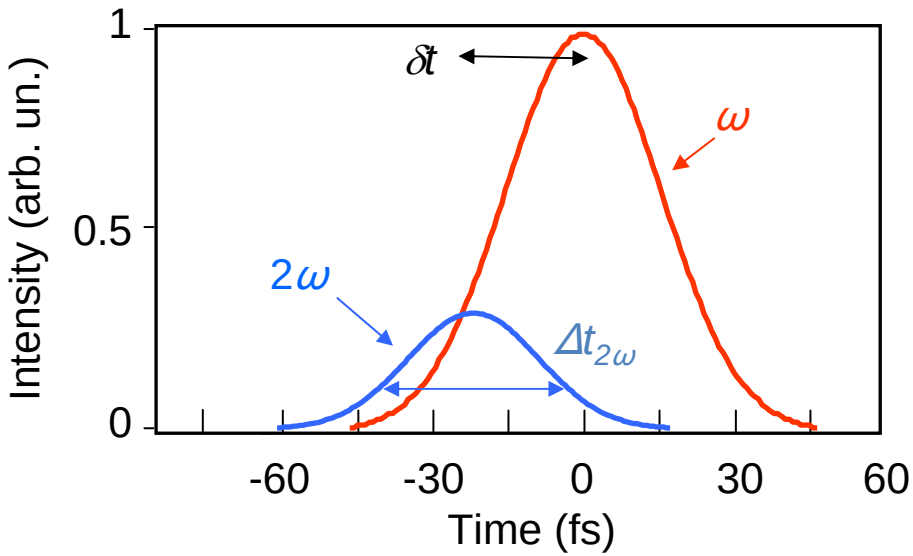
-redshift: $E_{Cut-off} = I_P + 3.2U_P$

$U_p \propto I_{Laser}\lambda^2_{Laser}$

-increase of the number of photons

General set-up



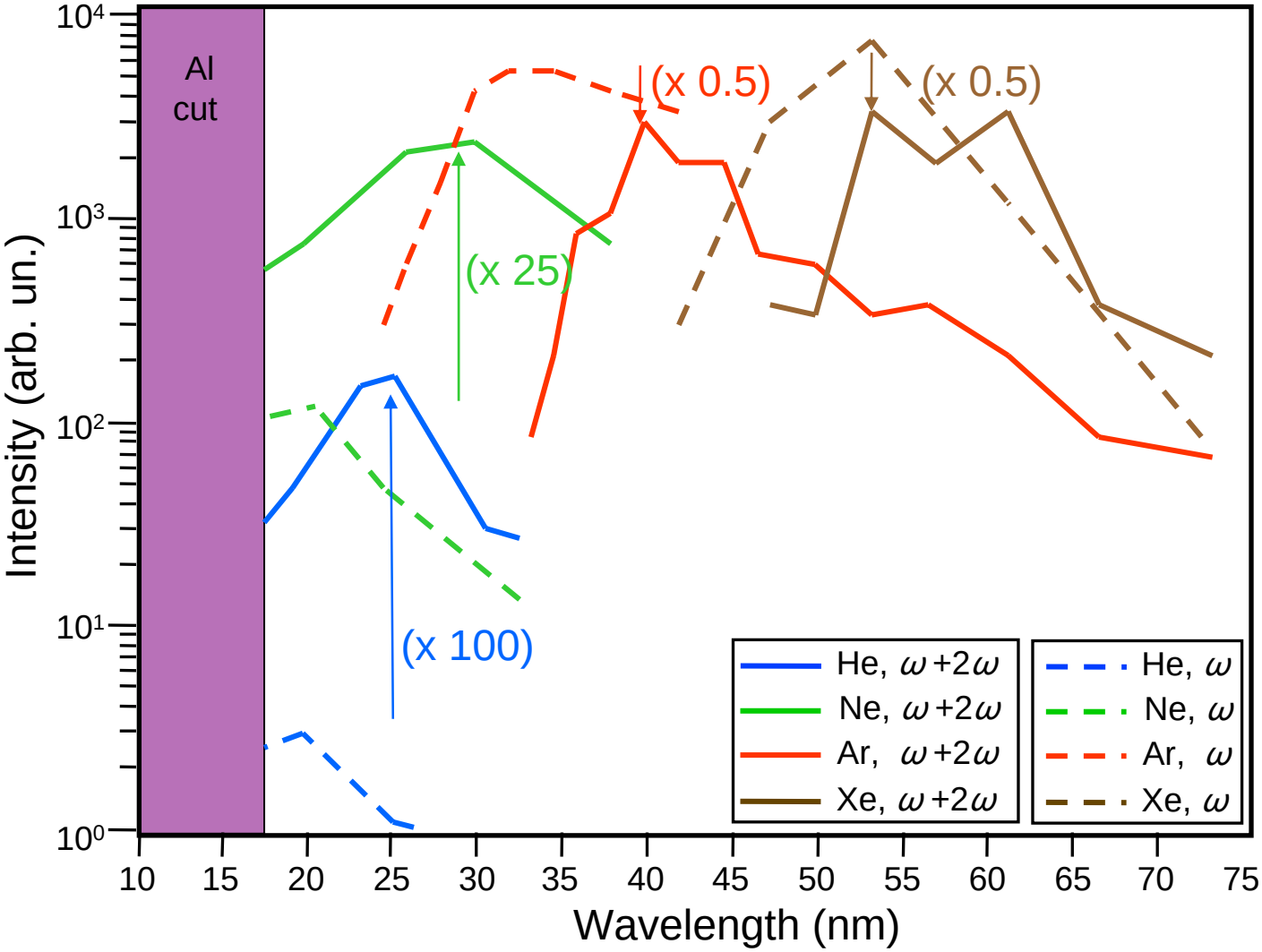


Simple system but only relative control on the 2nd harmonic generation parameters (mainly the BBO thickness):

- $-I_{2w}/I_w$ (also depending on the laser intensity)
- Temporal shift (δt): 18 fs every 100 μm
- $-\Delta t_{2w}/\Delta t_w$ (also depending on the laser chirp)

Harmonic spectra obtained with either ω or ω+2ω technique

100 µm thick BBO crystal, and with the optimization parameters corresponded to ω:
E_ω=6 mJ, L_C=7-9 mm and P_G=30-35 mbar



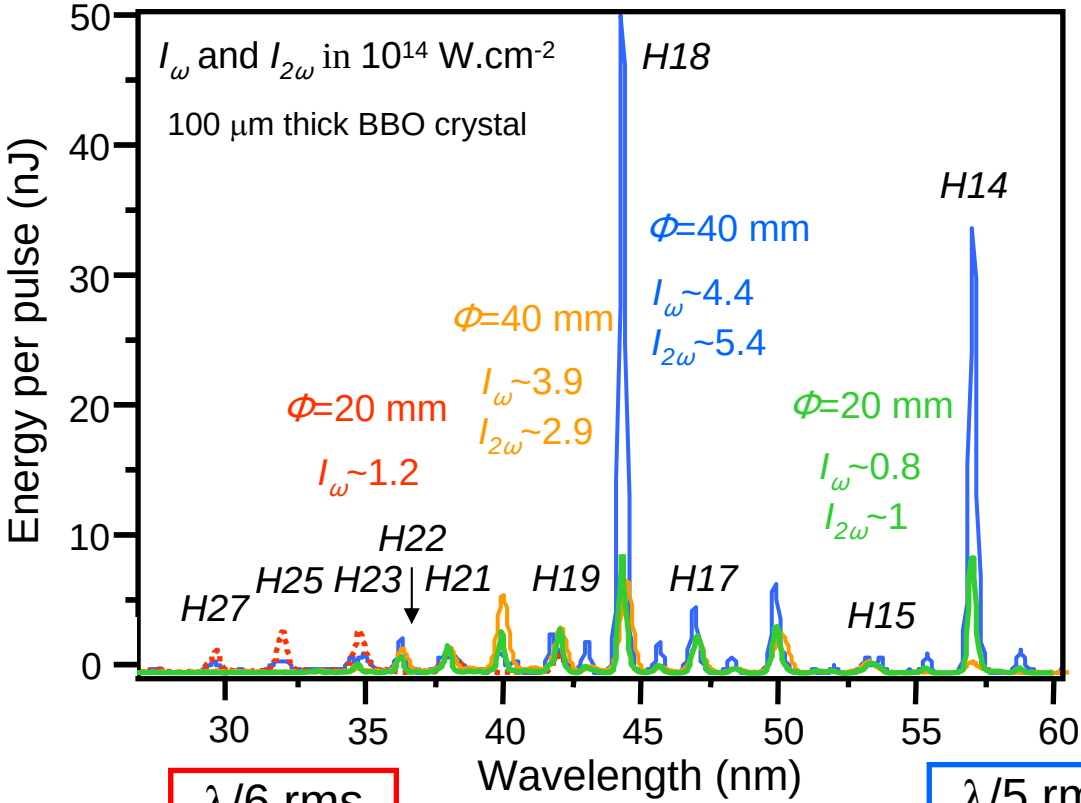
-Flat spectra (same intensity level for odd and even harmonics)

-Increase limited at high wavelengths due to an already relatively high efficiency for Xe and Ar

=> ω+2ω technique compensates the weak efficiency at short wavelengths

G. Lambert et al. to be published in New Journ. of Phys.

Optimization of the flux and of the wavefront (Ar gas)



-iris clipping technique:

change the focusing geometry/energy

clean the major part of the distortions in the outer part of the beam: λ to λ/6 rms

-ω (L_C=8 mm and P_G=30 mbar) to ω+2ω (L_C=4 mm and P_G=16 mbar)

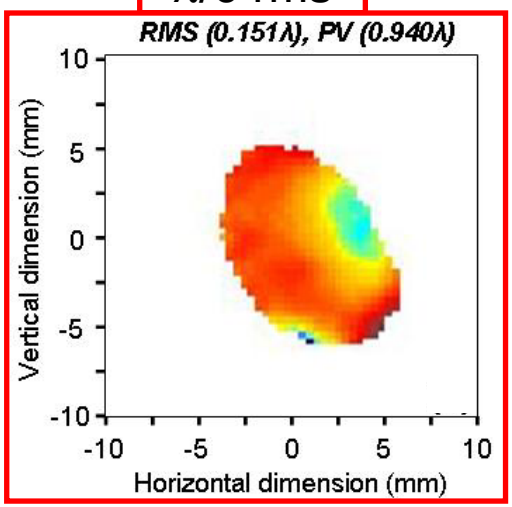
-very high increase on 2x(2n+1) type of even harmonics (50 nJ) due to strong blue/IR and distortions limited: λ/5 rms

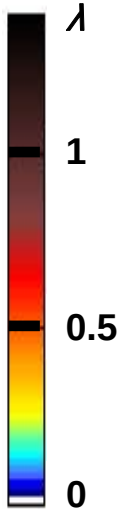
-iris clipping: limited decrease of intensity

But distortions about λ/17 rms:

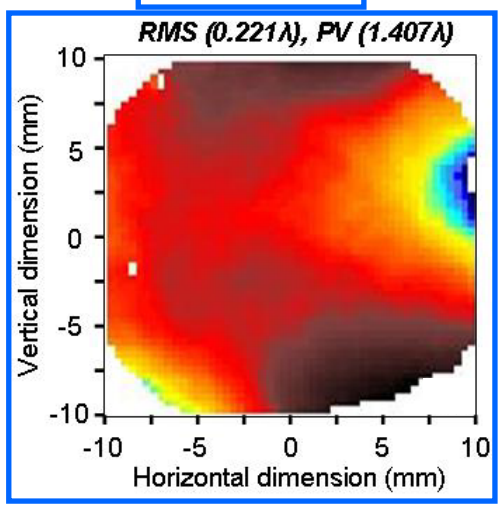
<u>First aberration-free high harmonic beam</u>

λ/6 rms

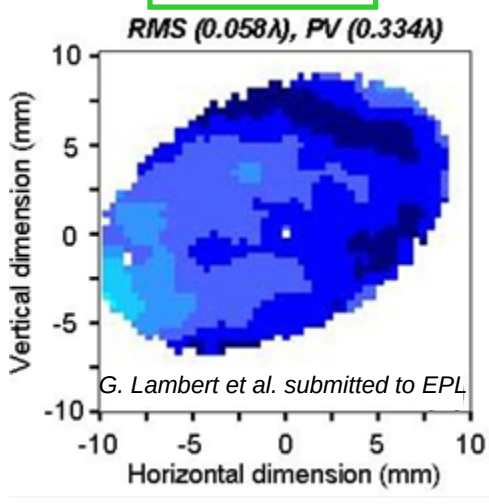




λ/5 rms



λ/17 rms



Summary of the two-colour HH properties

Already obtained	To be improved
-fs pulse duration	-Stability of the shot to shot intensity?
-Full coherence	
-High repetition rate: kHz to MHz soon	
-Intensity at short wavelengths	
-Tuneability: both odd and even harmonics	
Use parametric amplifier (1.2-1.5 μm)	
-Wavefront: aberration-free beam	
-Simple system	

Thank you
for your attention

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Imagin Optics

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