Centre - Énergie Matériaux Télécommunications

INRS
Université d'avant-garde

High-flux soft X-ray sources

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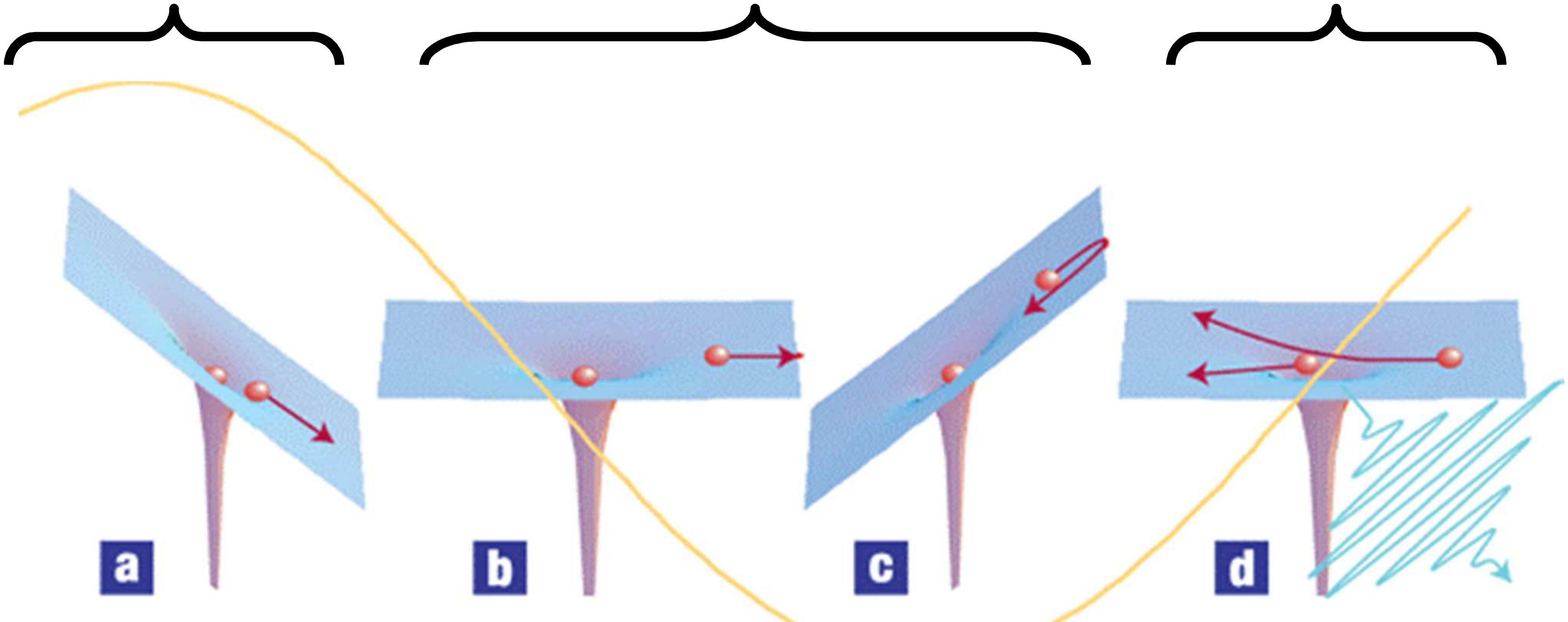
INRS-ÉMT

ALLS
Advanced Laser Light Source

High Harmonic Generation



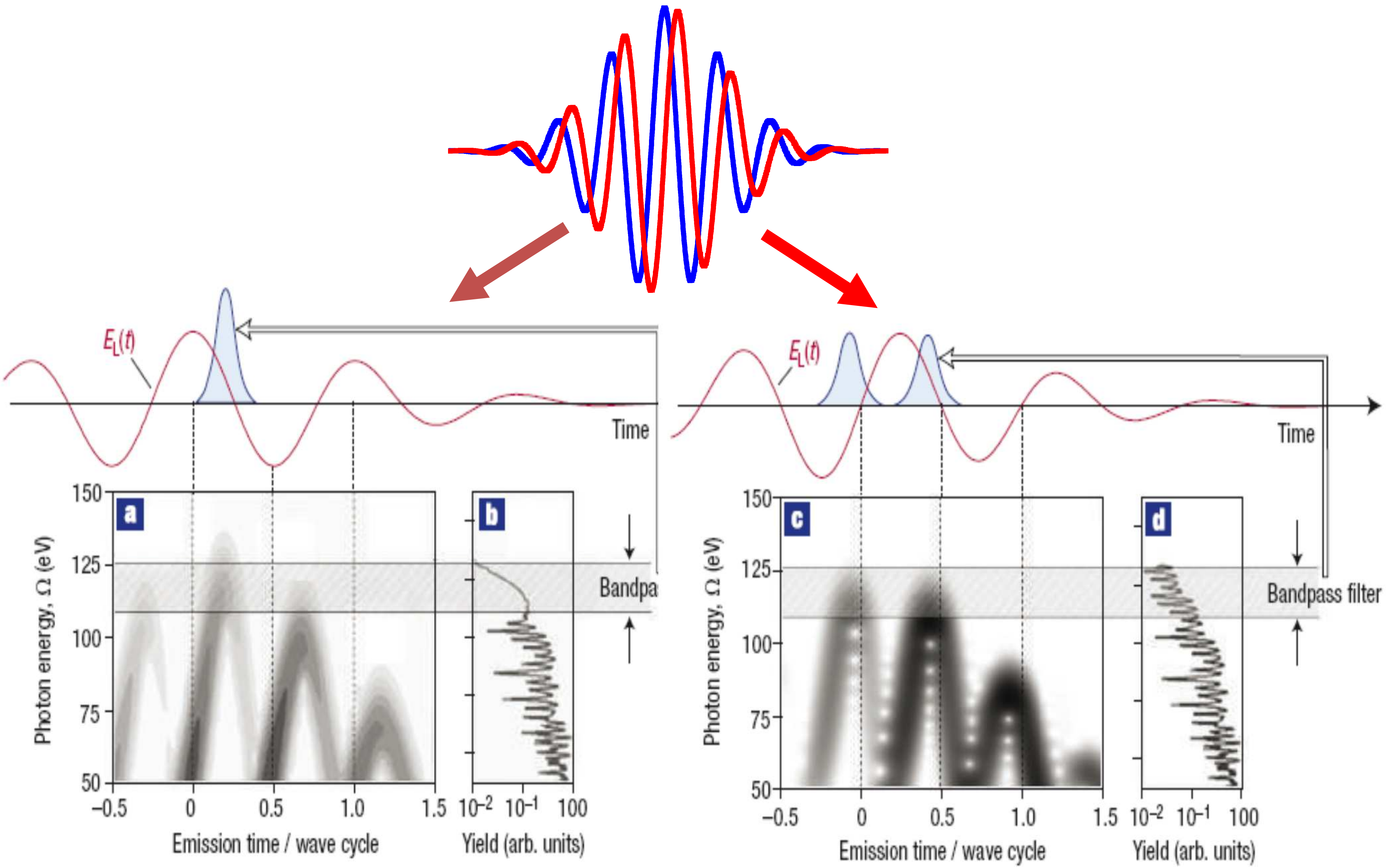
Tunnel Ionization

Electron acceleration

Recombination
& X-ray generation

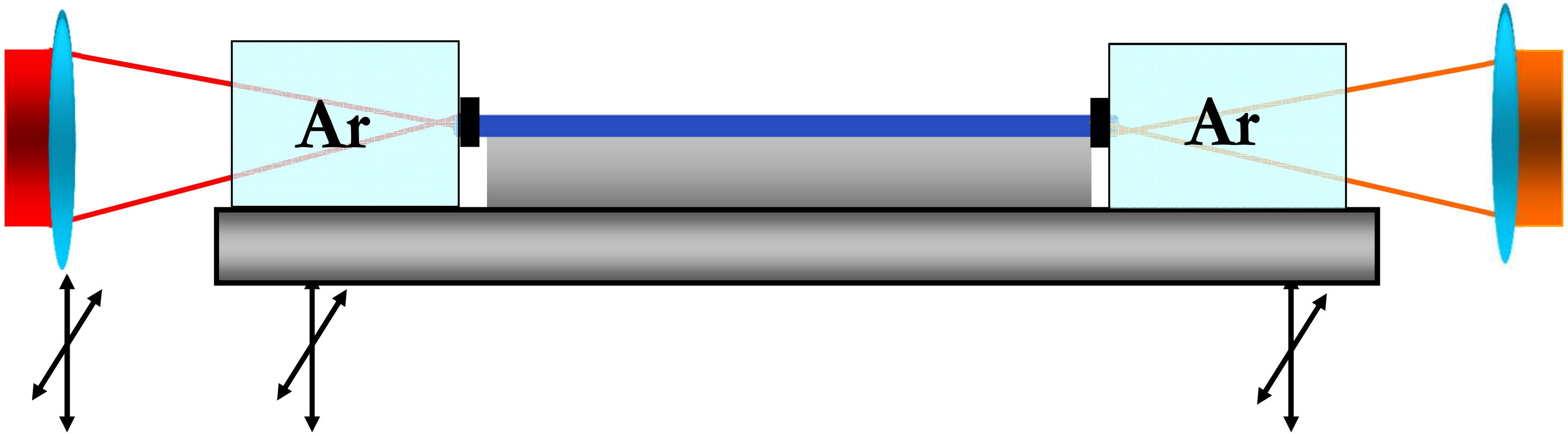
$U_p = I\lambda^2$; $h\nu = I_p + 3.17U_p$
$U_p = 300$ eV @1800 nm 10^{15} W/cm^2

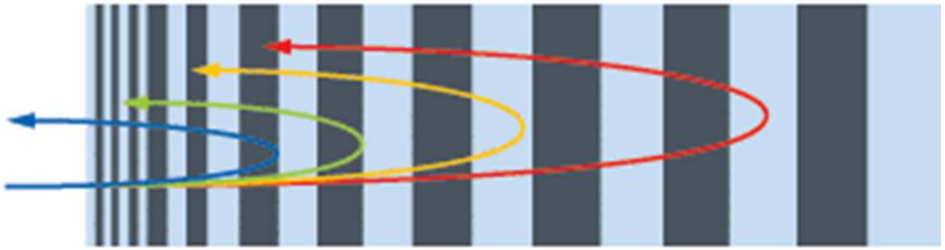
Corkum and Krausz, Nat. Phys. 2007.

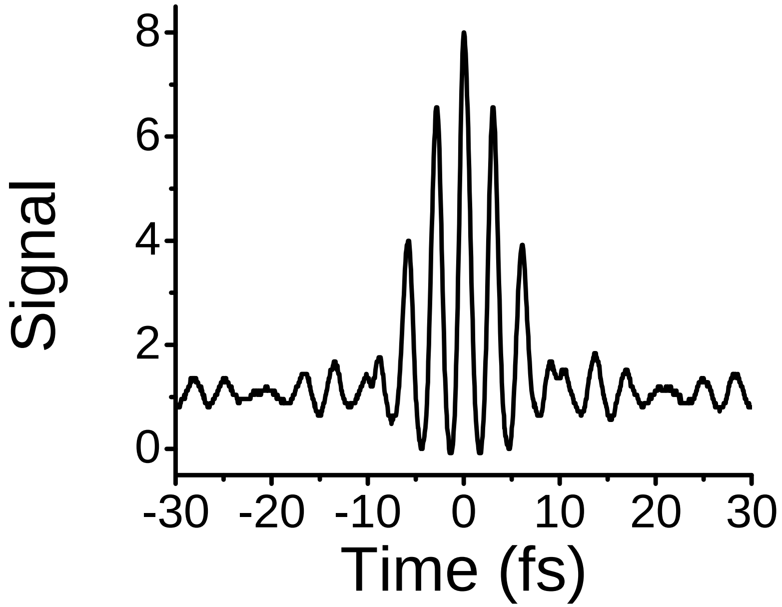


Corkum and Krausz, Nat. Phys. (2007).

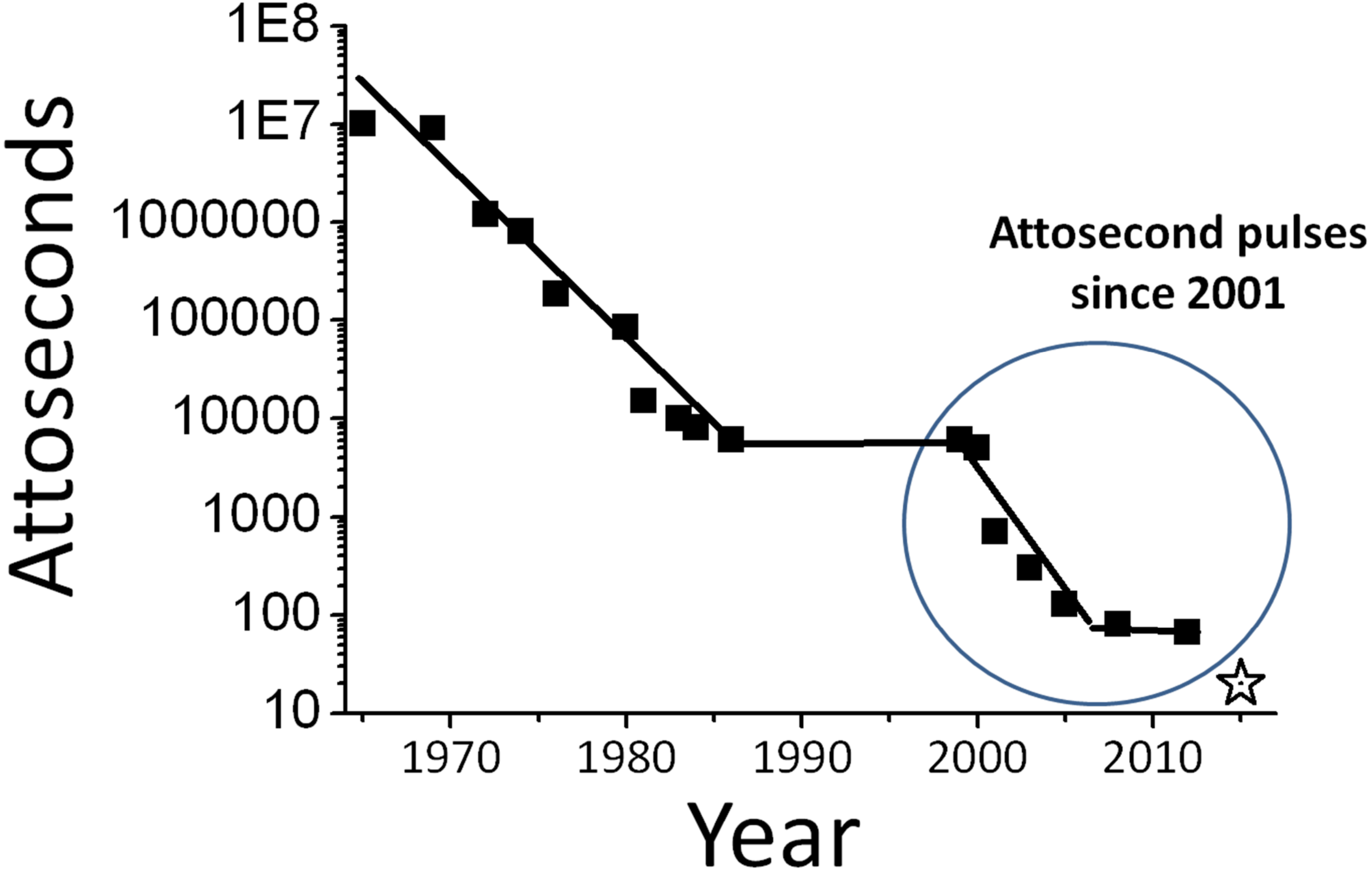
Few-cycle laser pulses @ 800 nm



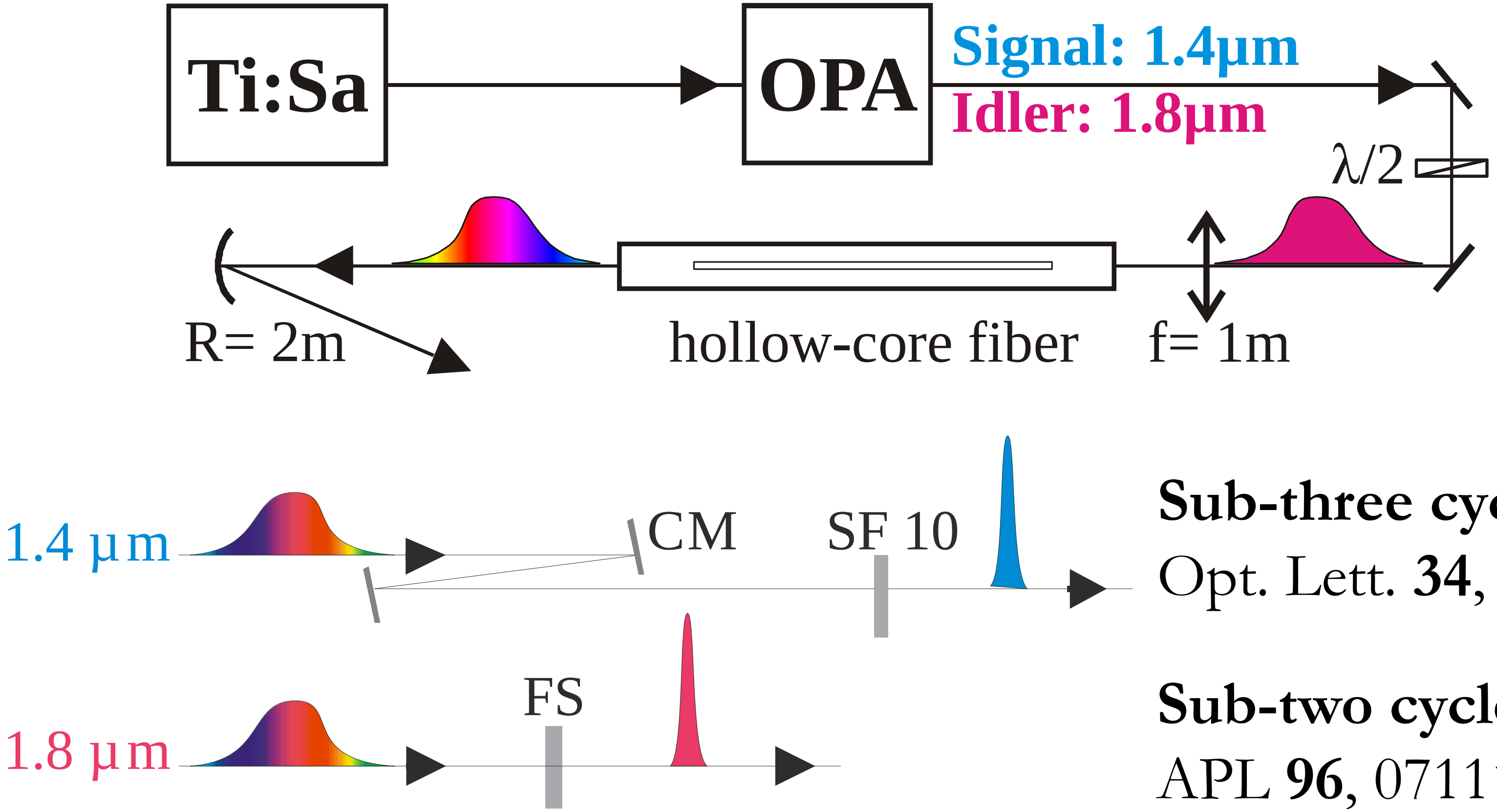




Laser pulse duration since the 60s



Experimental setup for few-cycle IR

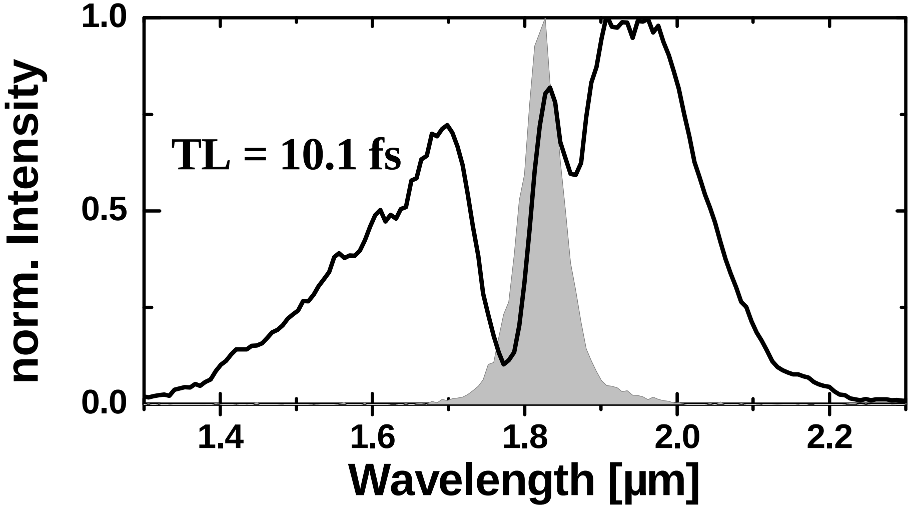


Sub-three cycles:
Opt. Lett. **34**, 1894 (2009).

Sub-two cycles:
APL **96**, 071111 (2010)

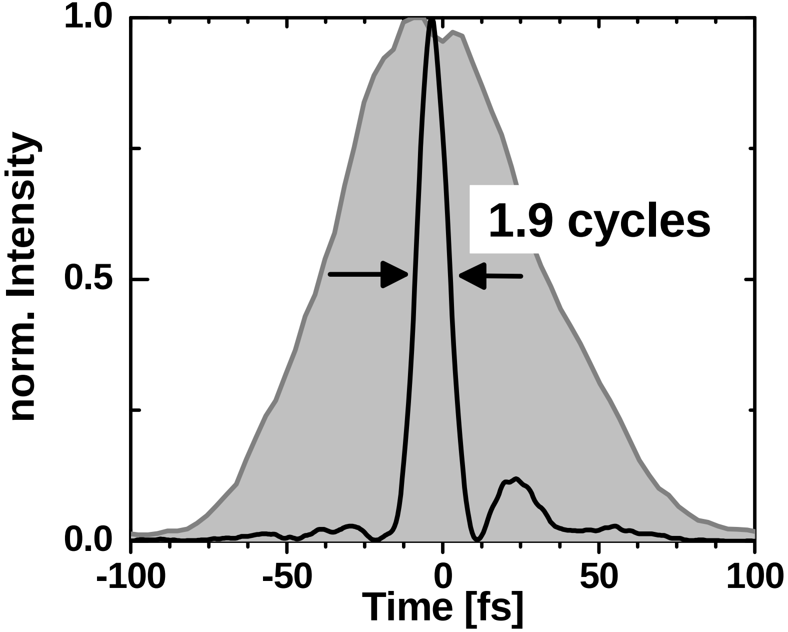
CEP stable 1.6 cycles:
Opt. Exp. **19**, 6858 (2011)

Idler pulse compression – 1.8μm



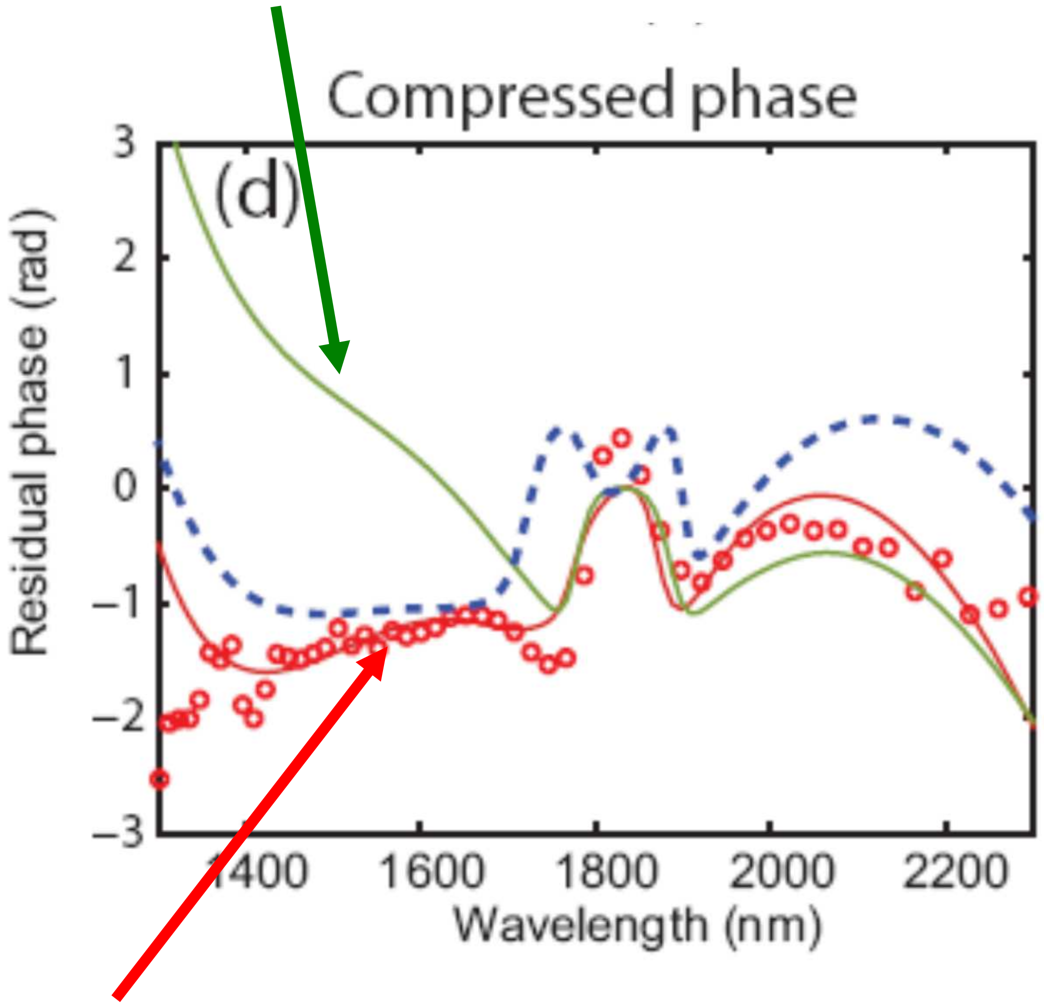
3 mm of
fused silica

100 Hz: 400 µJ, 11.5 fs @ 1.8 µm



B. E. Schmidt et al. APL **96**, 121109 (2010).

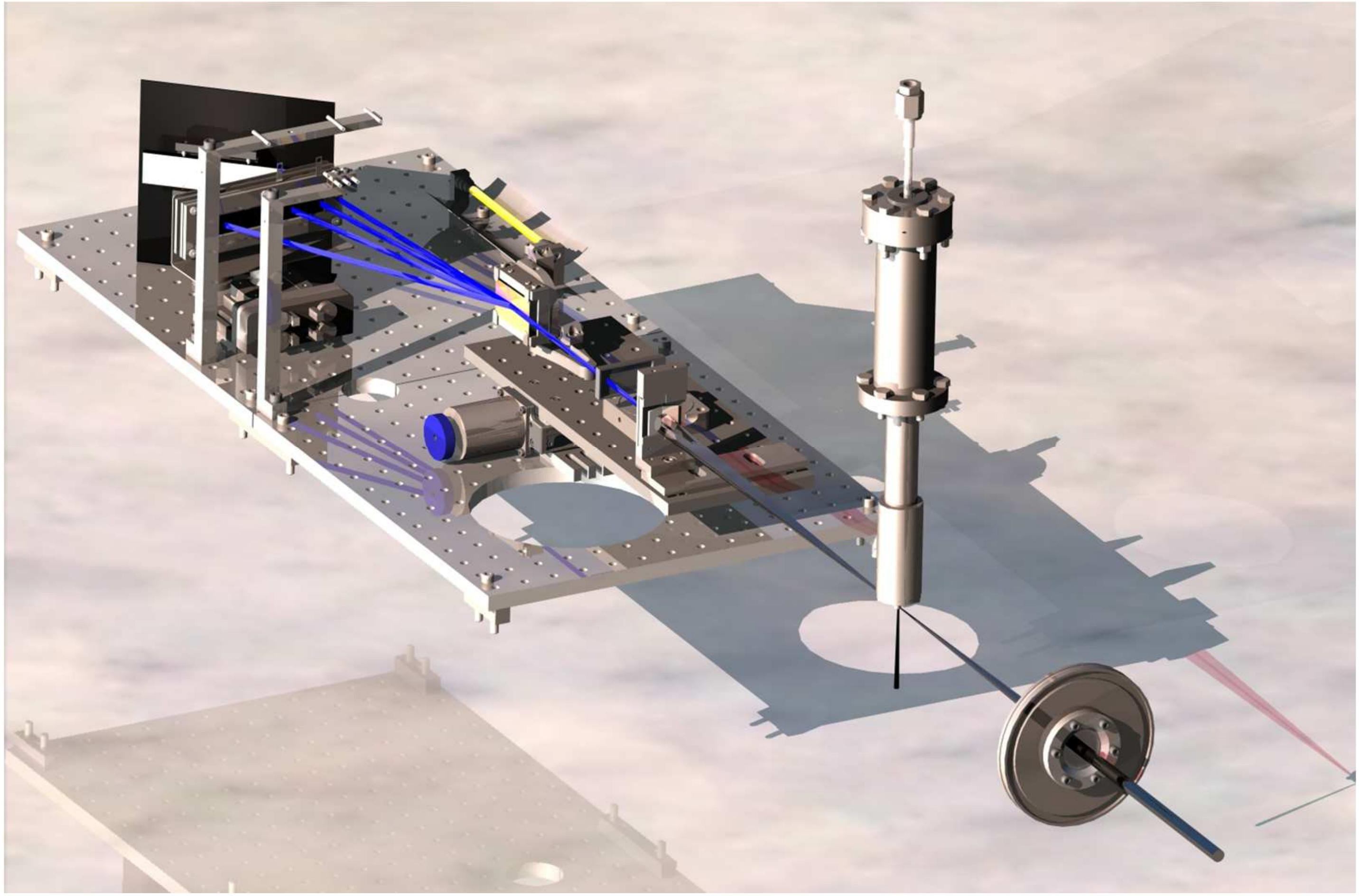
Only Self-Phase Modulation (SPM)



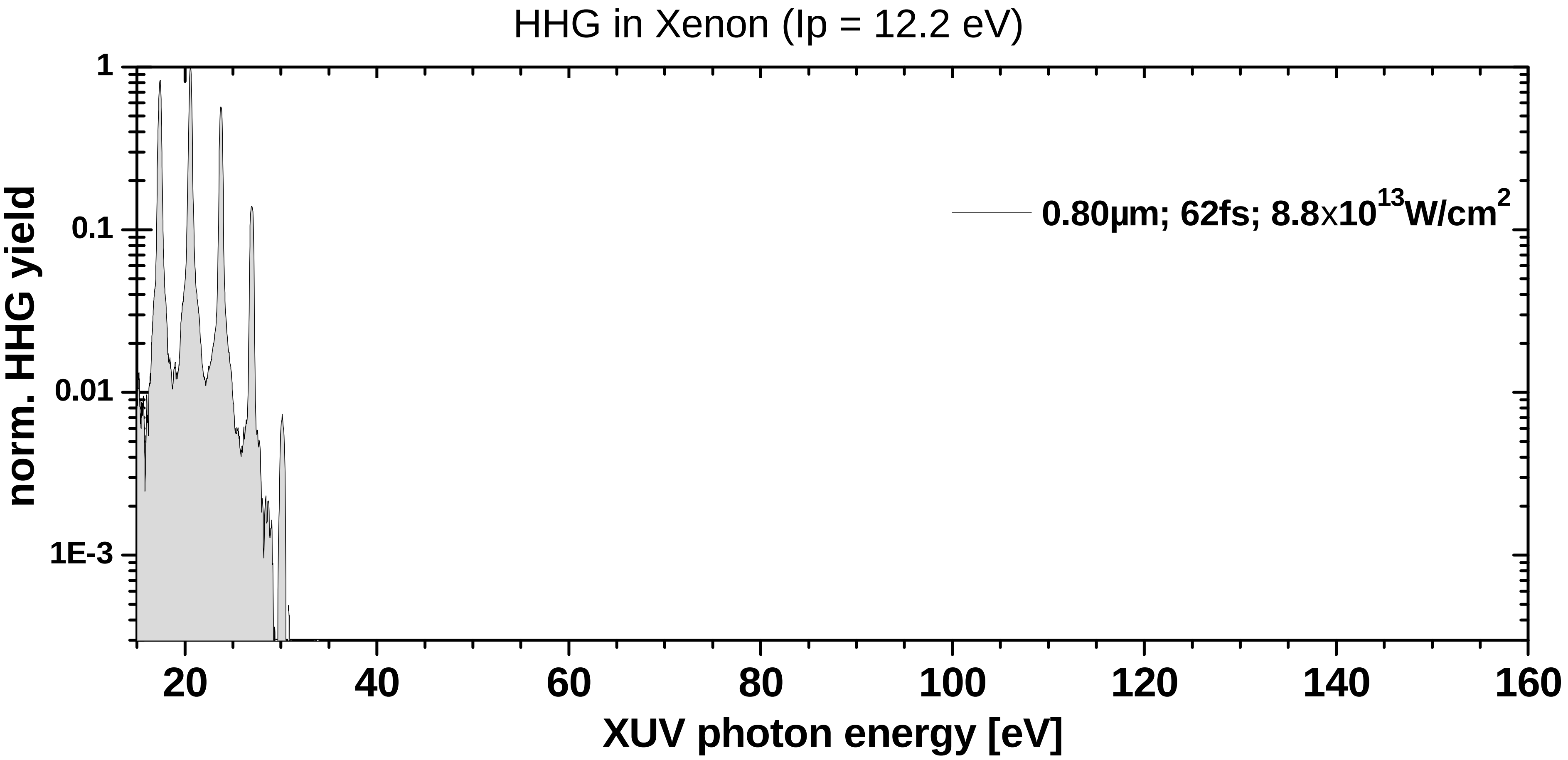
Full model: SPM + self-steepening

B. E. Schmidt et *al.* APL **96**, 121109 (2010).
P. Béjot et al. PRA **81**, 063828 (2010).

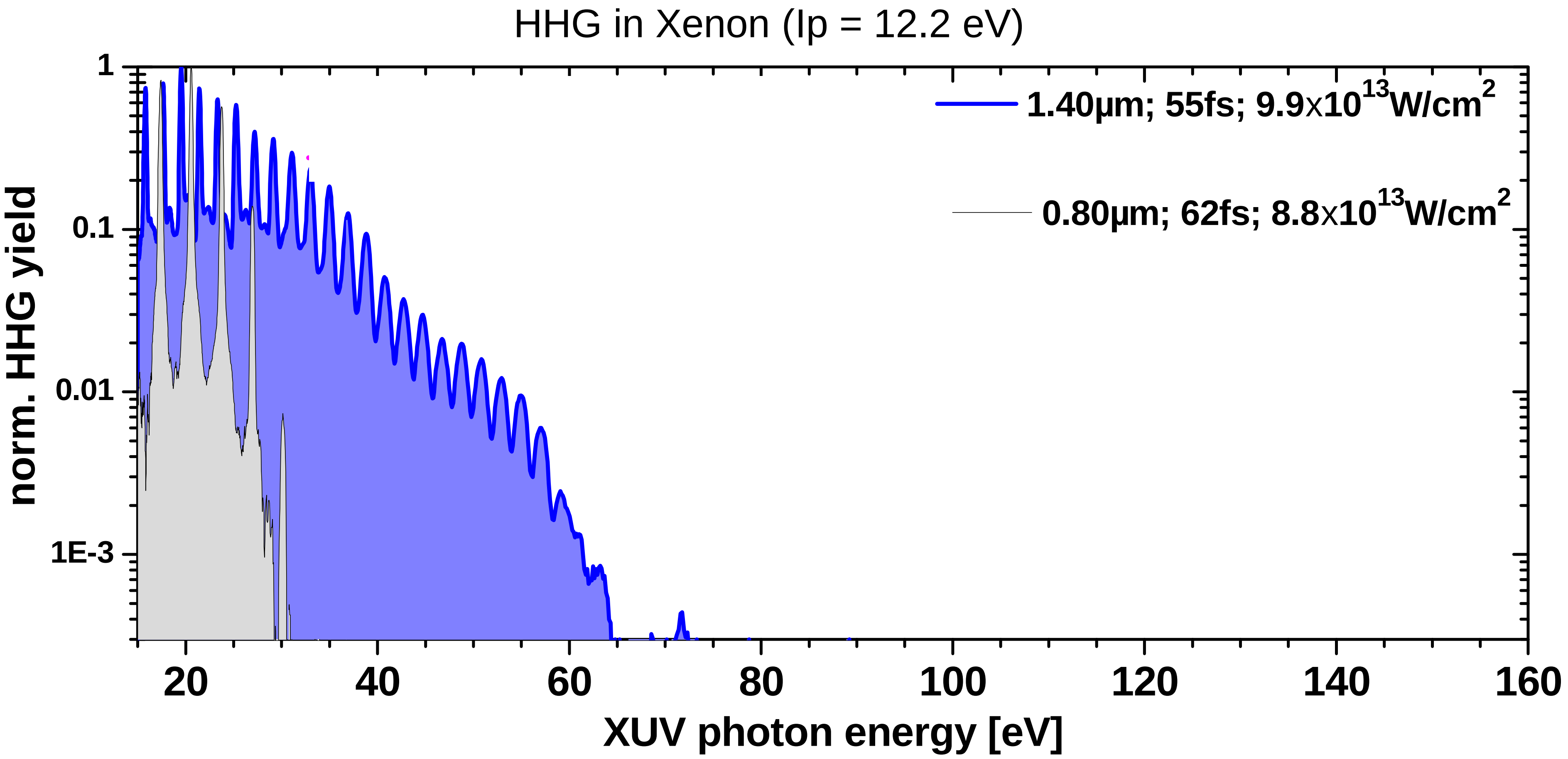
High harmonic generation



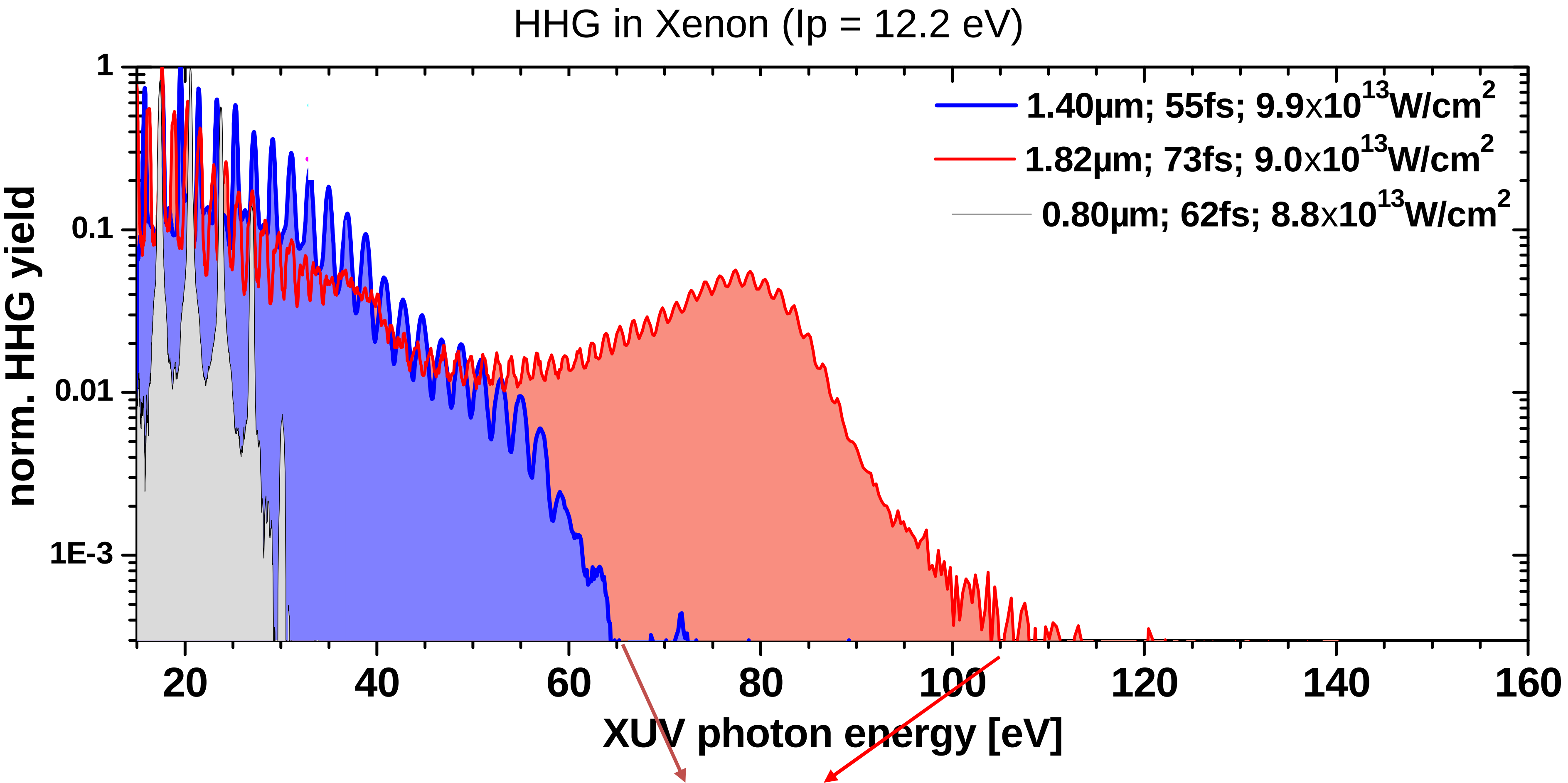
HHG with IR few-cycle pulses



HHG with IR few-cycle pulses

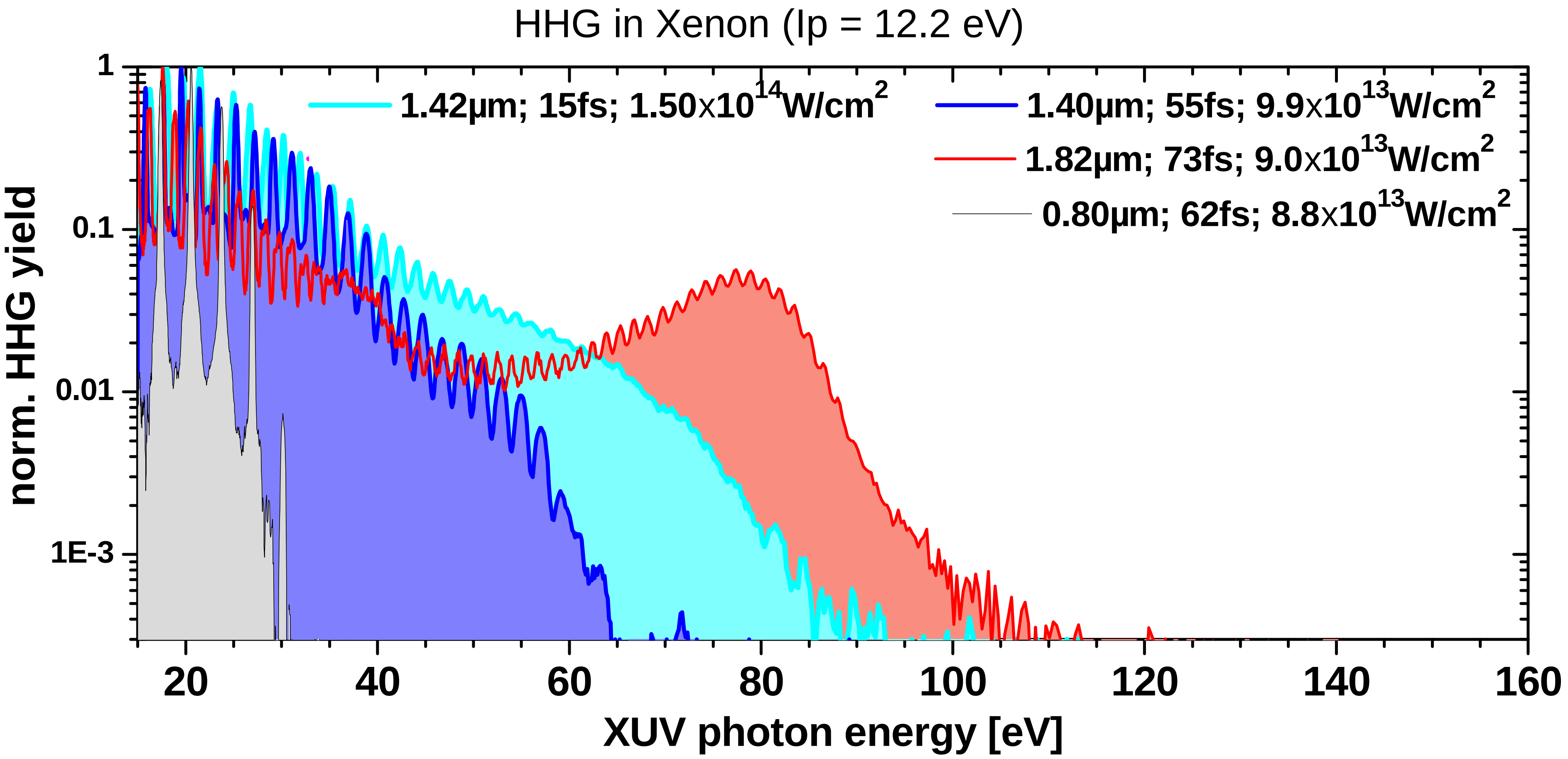


HHG with IR few-cycle pulses

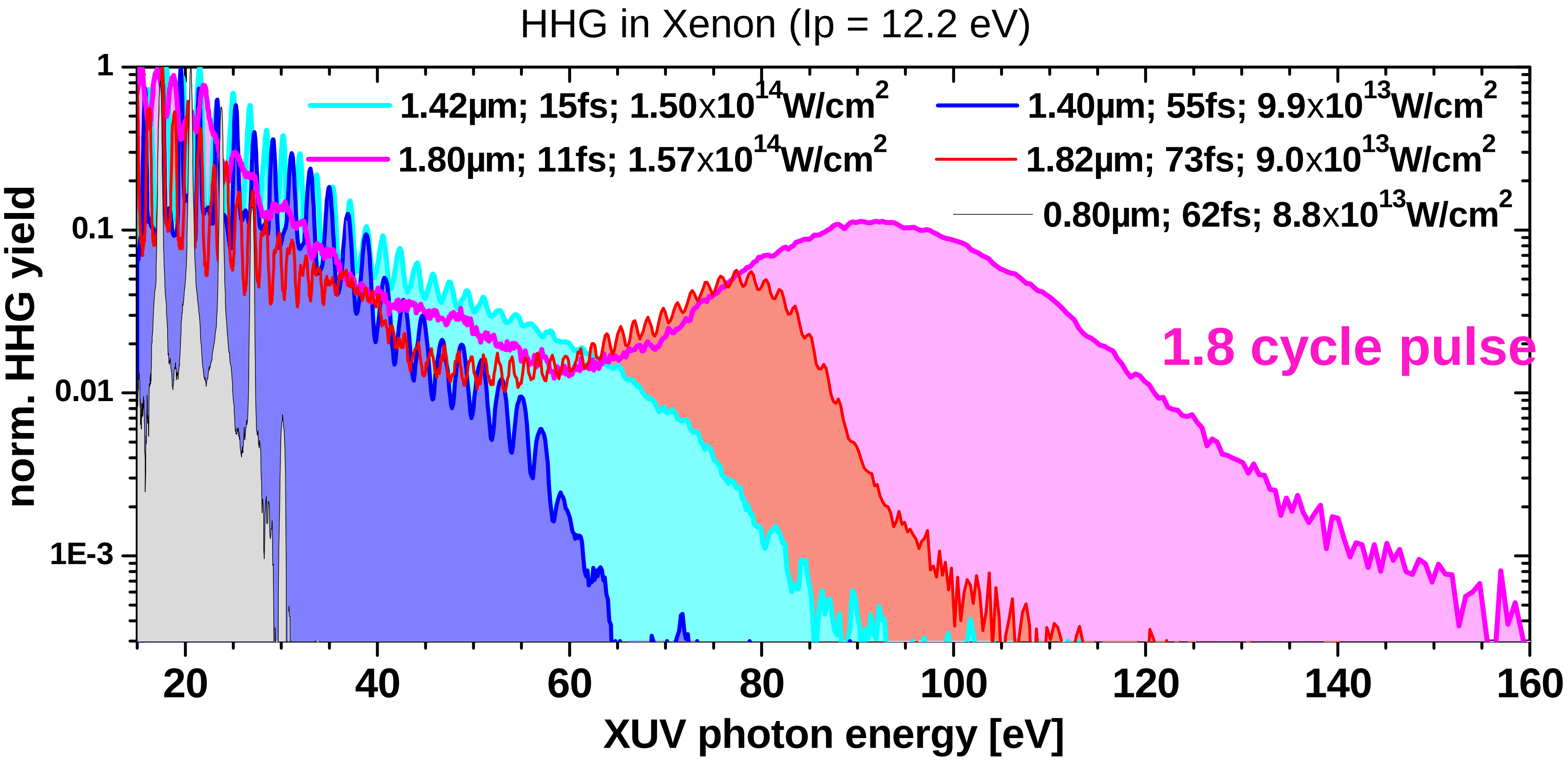


65eV / **105**eV **= 0.62 ≈ (1.4**µm / **1.8**µm**)^2 = 0.60**

HHG with IR few-cycle pulses



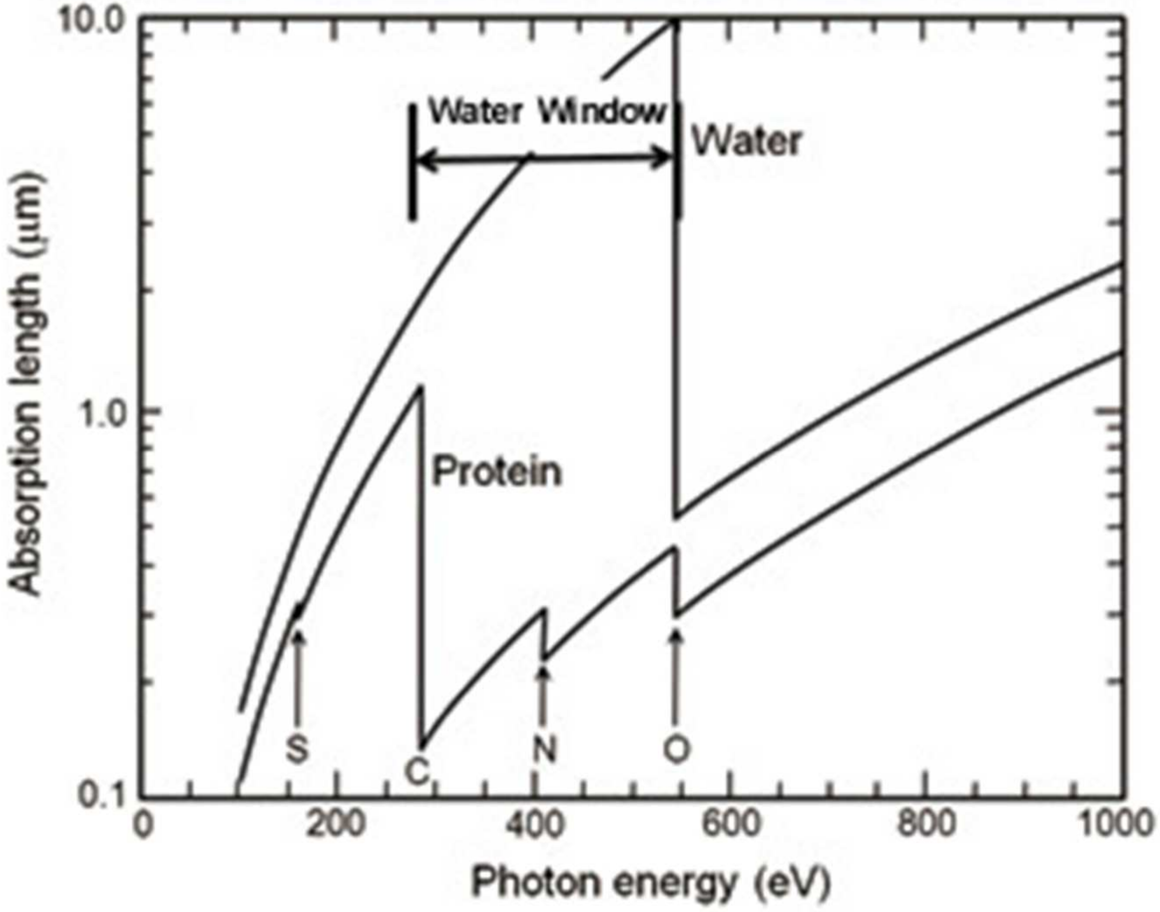
HHG with IR few-cycle pulses



A. D. Shiner et al. *Nat. Phys.* **7**, 464-467 (2011).

B. E. Schmidt et al. *J. Phys. B: At. Mol. Opt. Phys.* **45**, 074008 (2012).

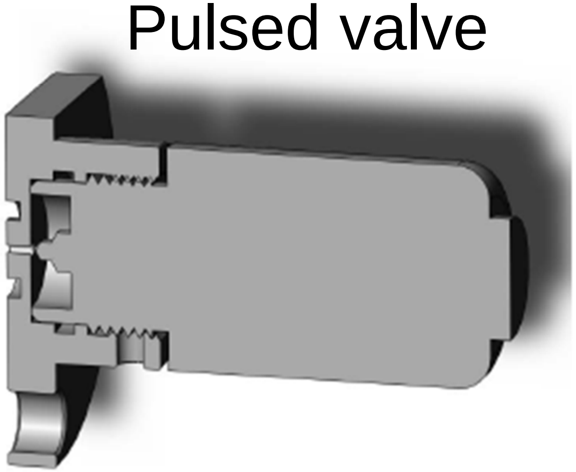
High brightness soft X-ray pulses in the water window



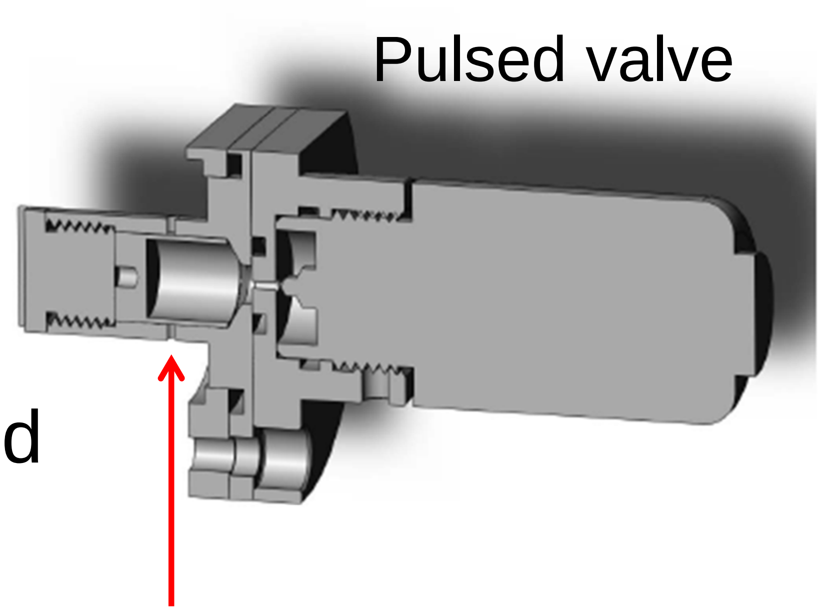
High density pulsed-gas-cell

- Short interaction length (0.5 mm)

- Backing pressure limited by vacuum (low density)

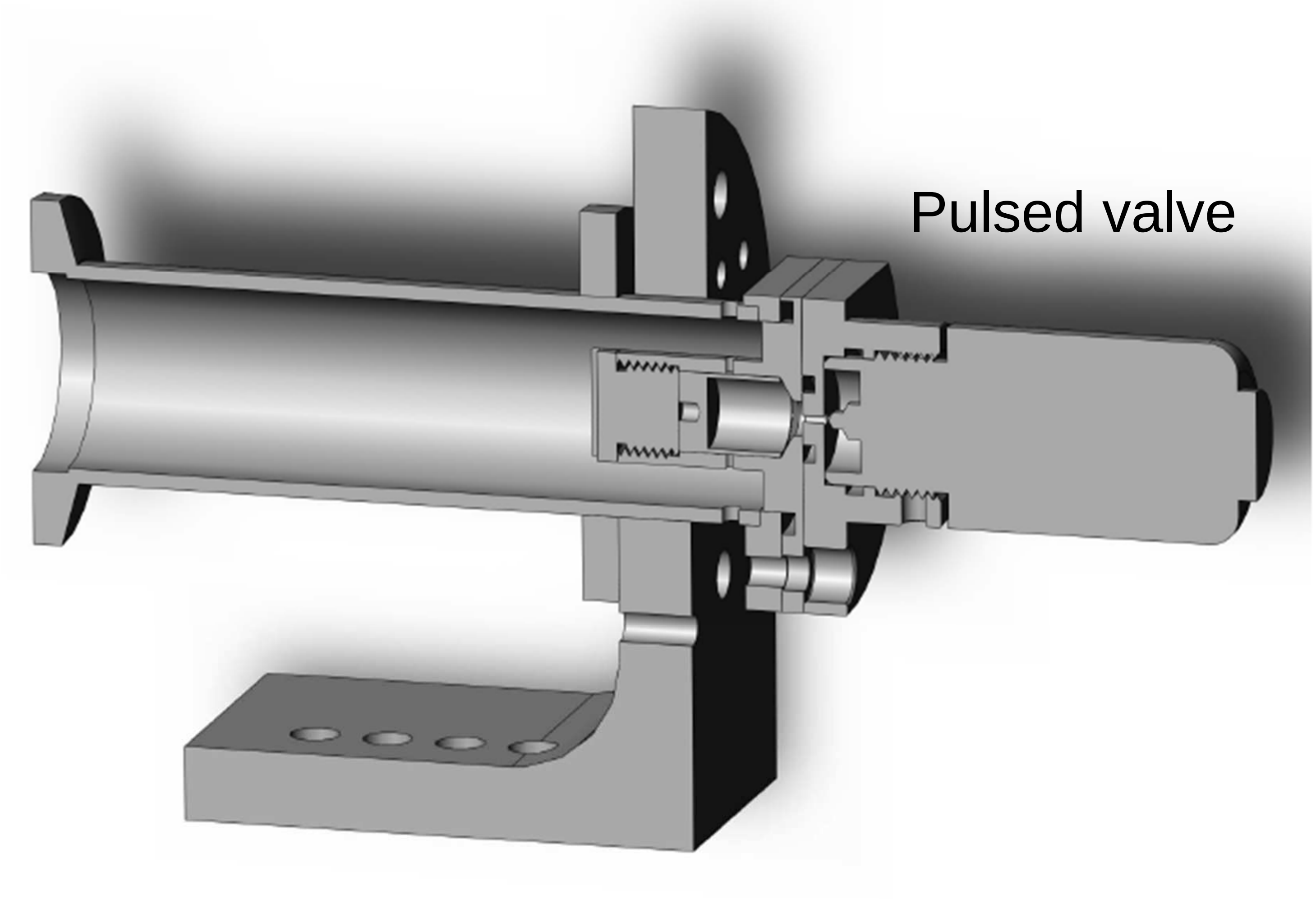


High density pulsed-gas-cell



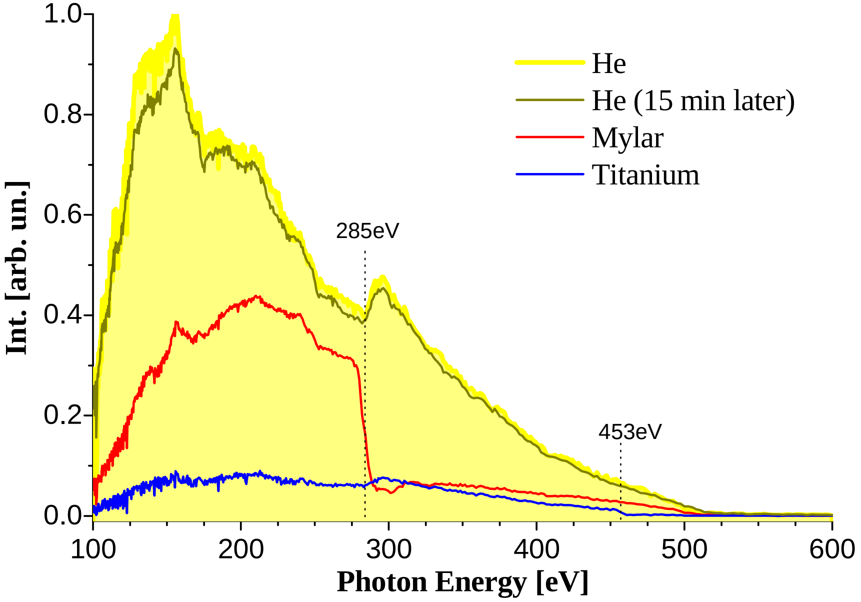
-Backing pressure limited by vacuum

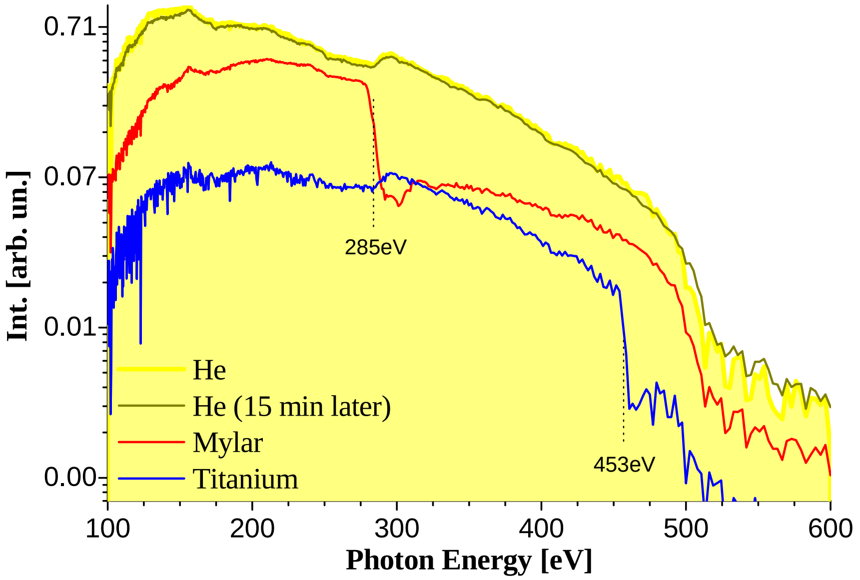
High density pulsed-gas-cell



Absorption Edges

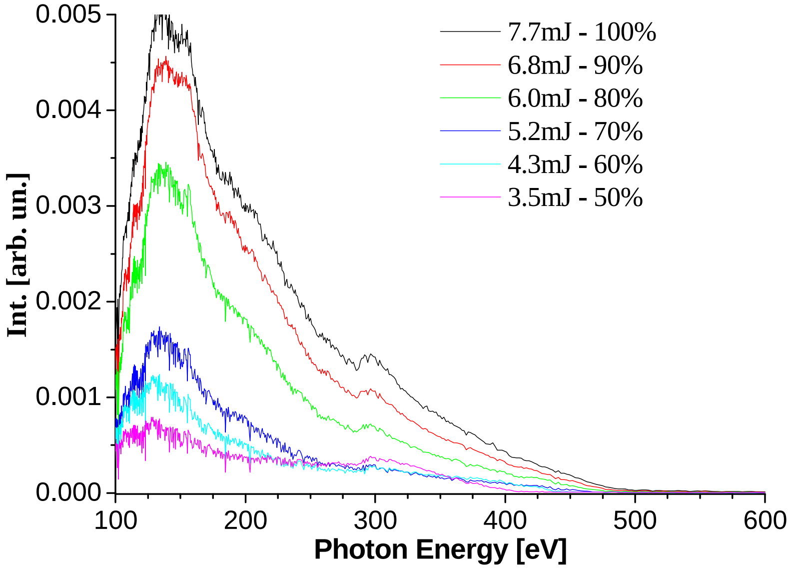
He, 8mm Cell, 650 PSI

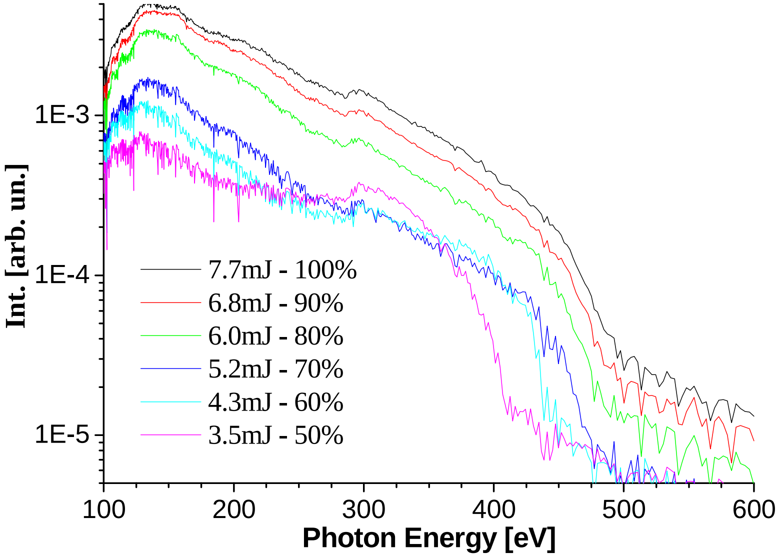




Intensity Scan

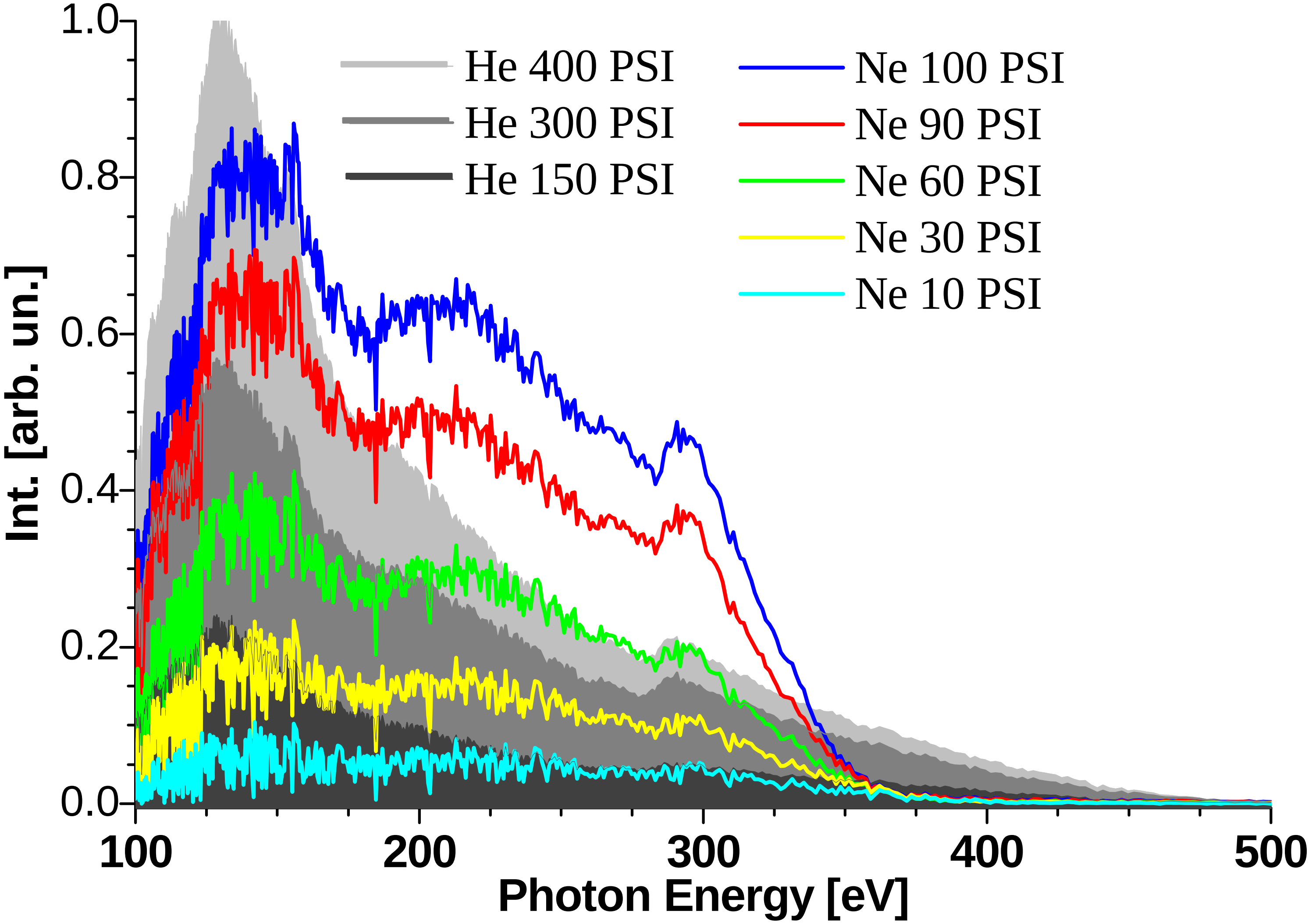
He, 8mm Cell, 350 PSI



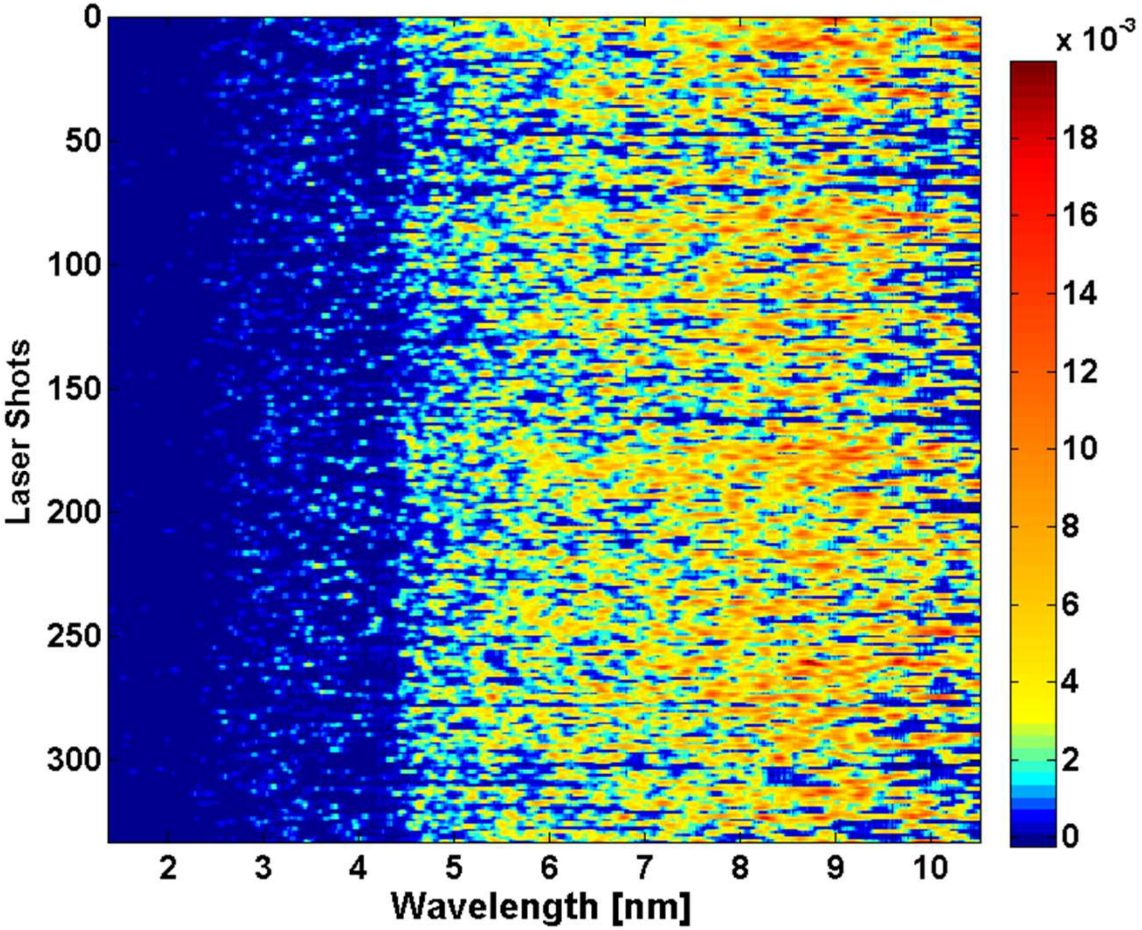


He / Ne Comparison

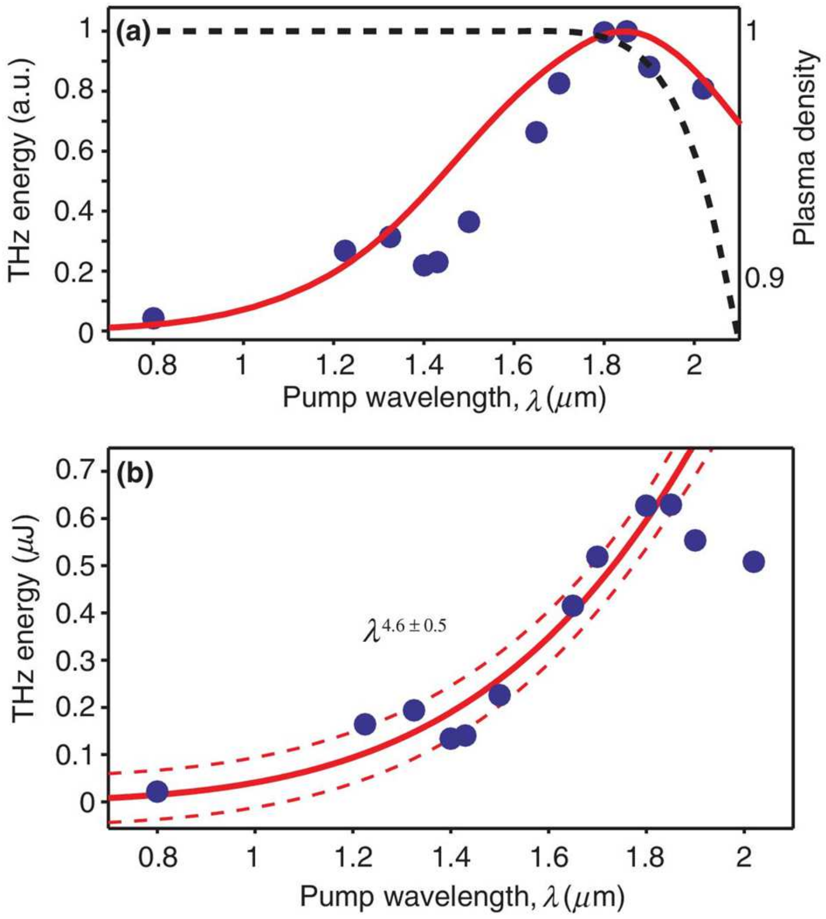
8mm Cell



Single shot carbon k-edge



THz generation with ω/2ω



Wavelength dependent parameter:

- Transverse plasma photocurrent $\propto \lambda^2$
  Proportionnal to the
  ponderomotive force ($I\lambda^2$)

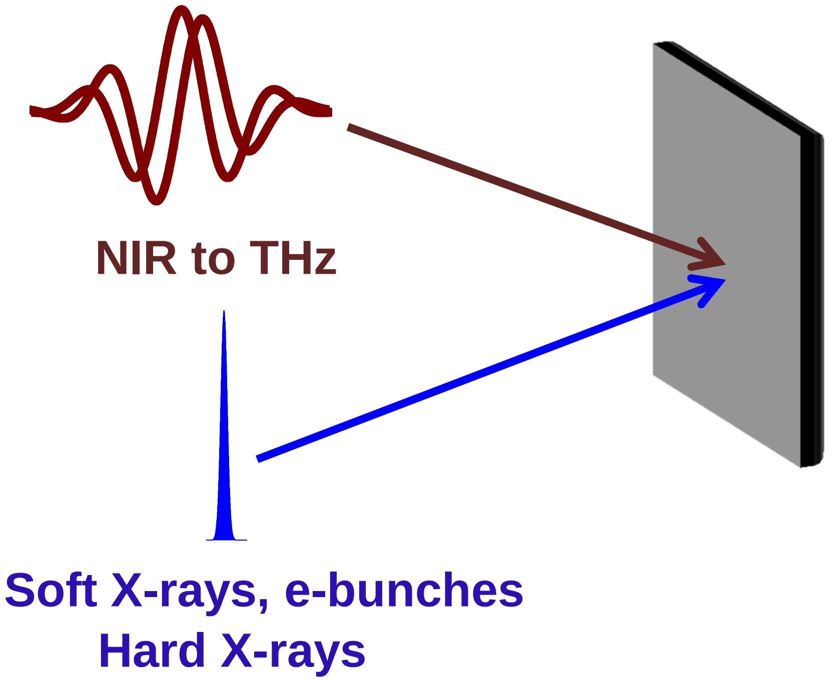
- Plasma volume $\propto \lambda^3$
  Rayleigh range
  Beam diameter at focus

$$I_{THz}(\lambda) \propto \lambda^{4.6 \pm 0.5}$$

Single cycle THz pulses with 4.4 MV/cm

M. Clerici et al. *Phys. Rev. Lett.* **110**, 253901 (2013).

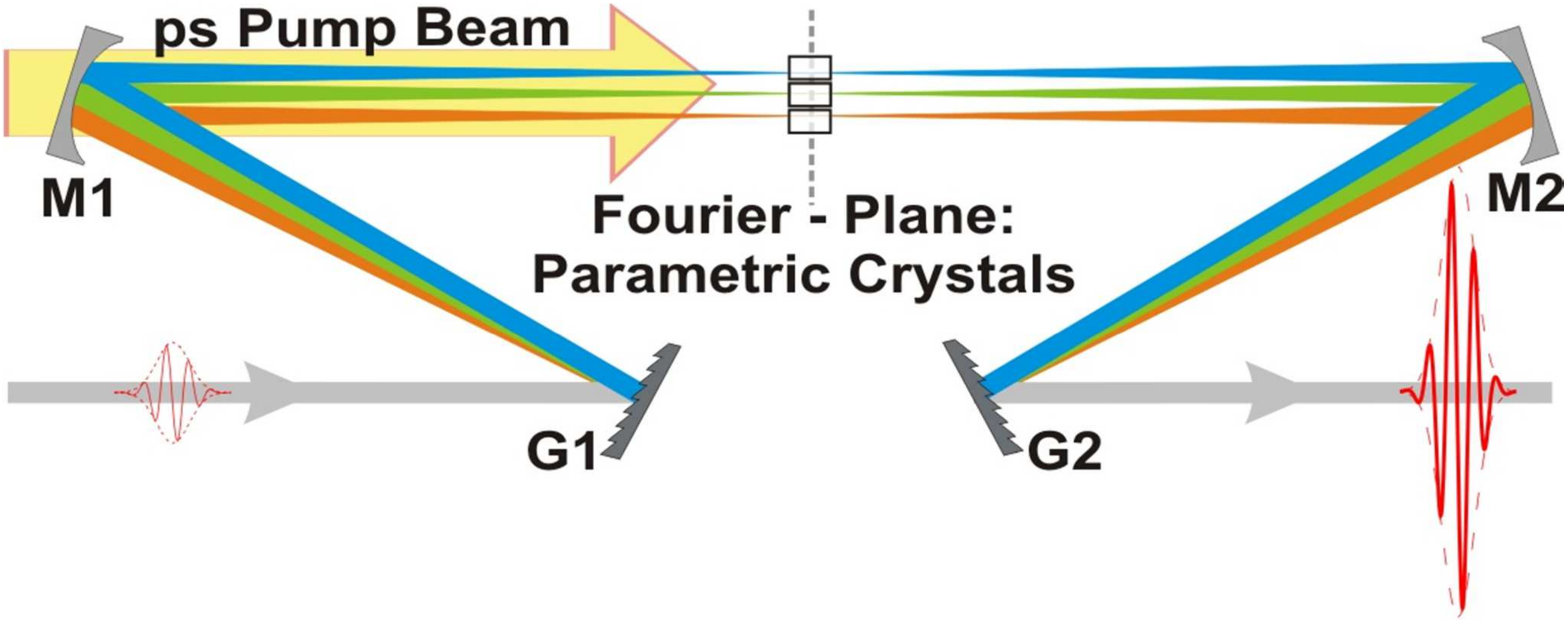
Dynamic imaging platform

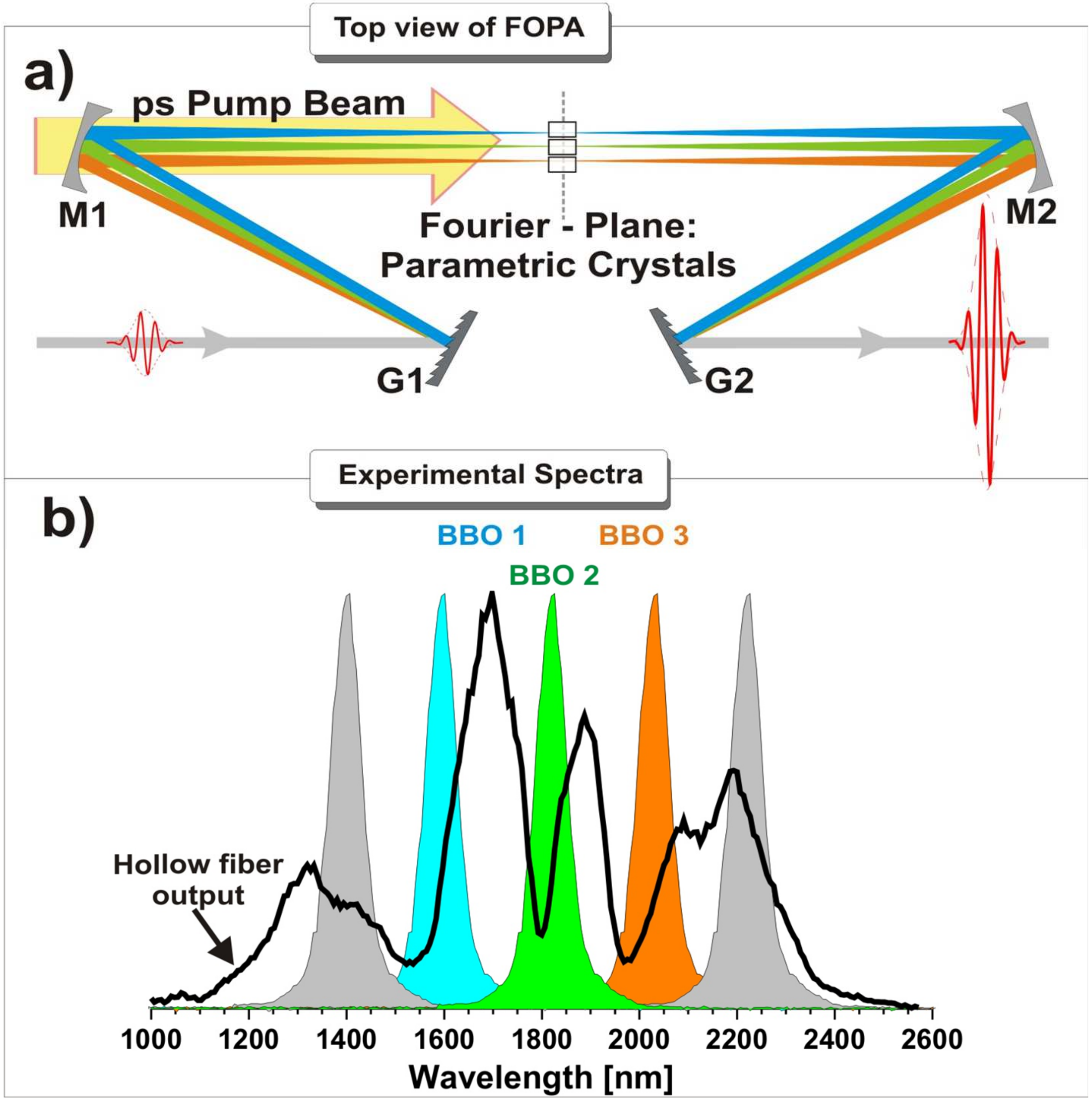


- Pumping with tunable CEP stable pulses from NIR to THz.
- Probing using time-resolved soft X-ray measurements
  - absorption
  - reflectivity
  - diffraction
  - photoelectrons
- Ultrafast electron diffraction imaging
- Ultrafast hard X-ray diffraction imaging

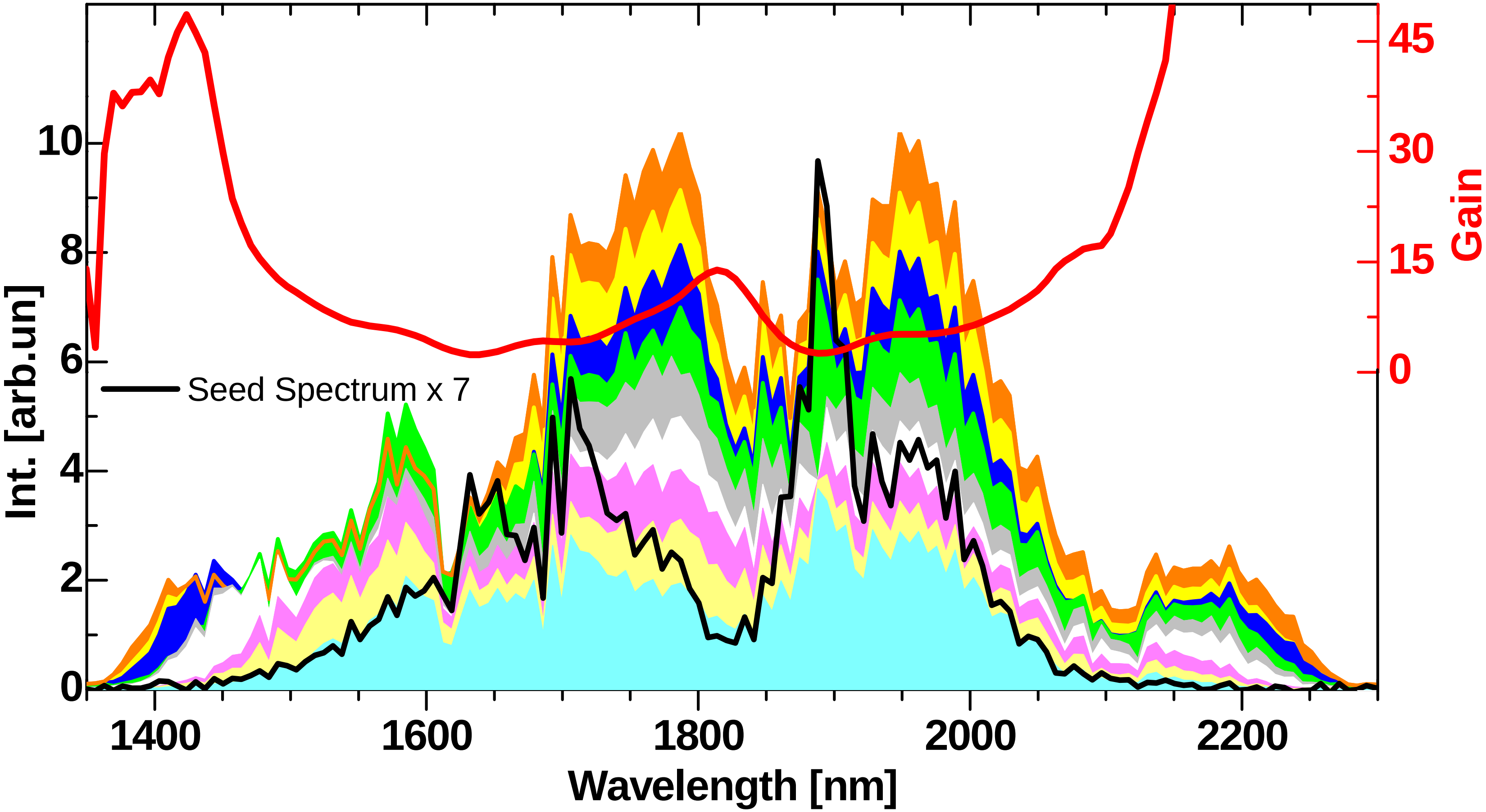
J. Weisshaupt et *al.* CLEO: 2014, OSA Technical Digest (online) (Optical Society of America, 2014), paper SM1F.5.

Frequency domain OPA

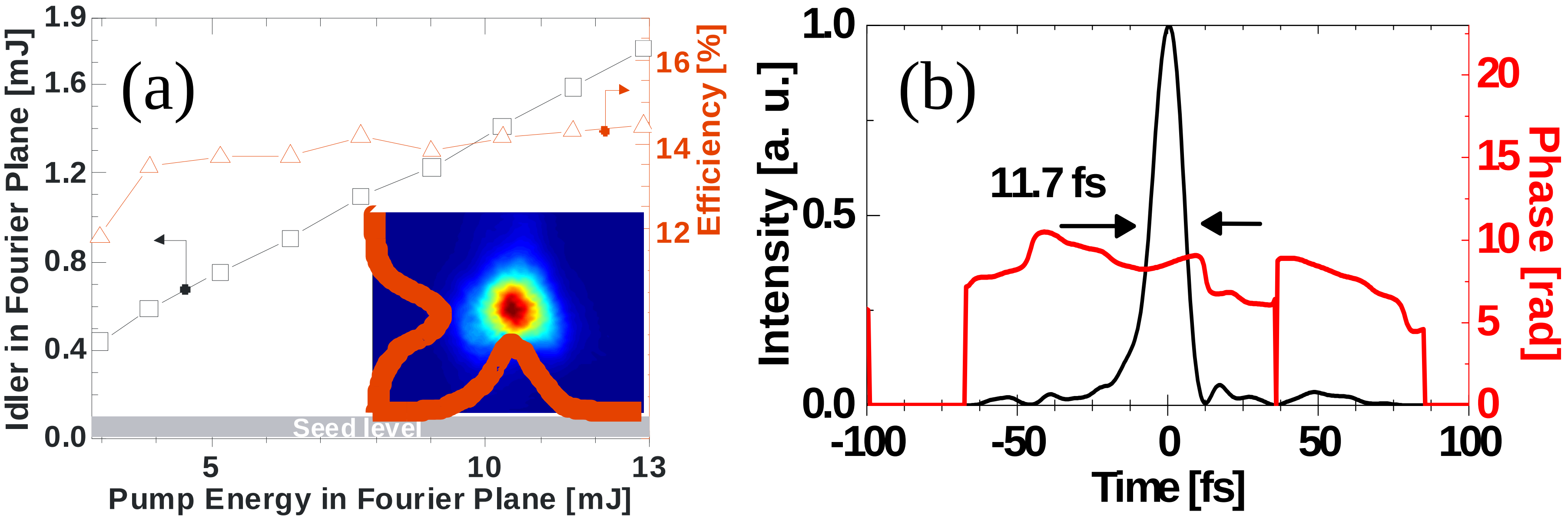


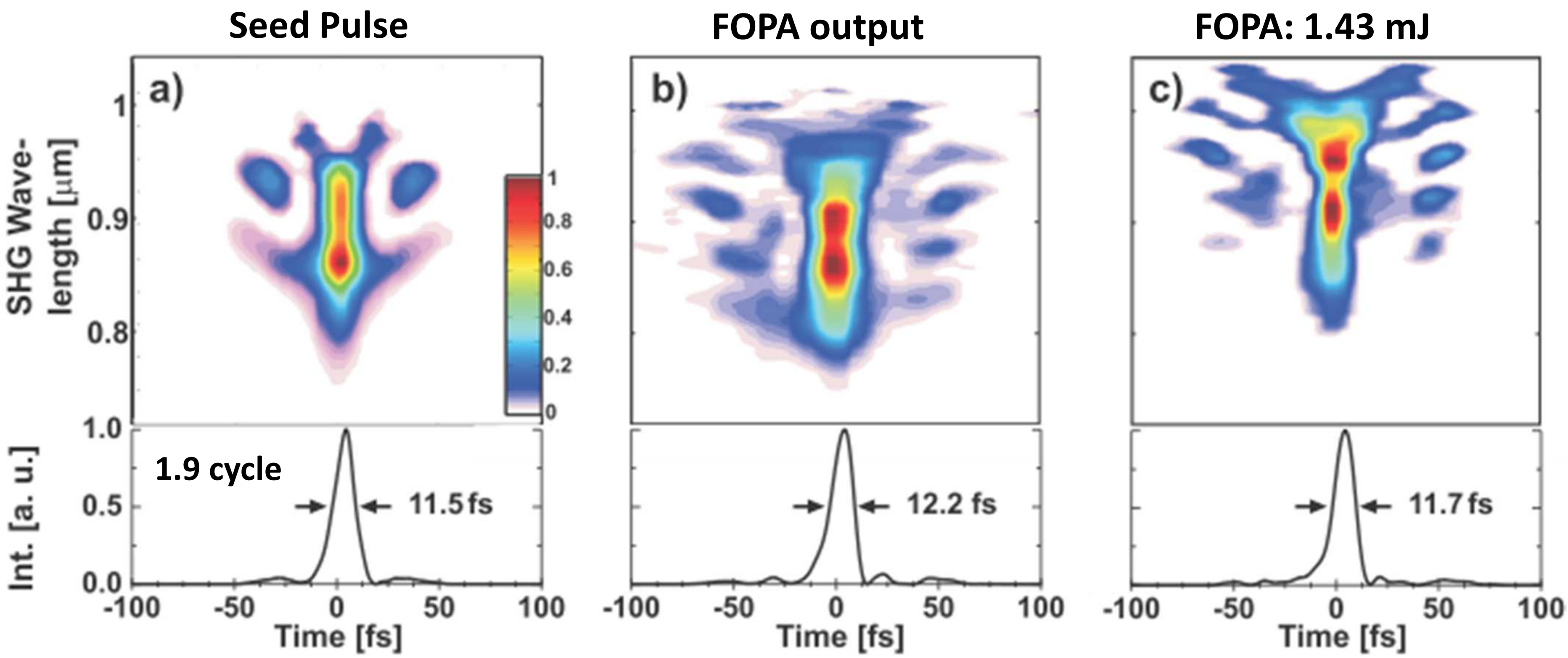

Top view of FOPA
a)
ps Pump Beam
M1
M2
Fourier - Plane:
Parametric Crystals
G1
G2
Experimental Spectra
b)
BBO 1
BBO 3
BBO 2
Hollow fiber
output
1000
1200
1400
1600
1800
2000
2200
2400
2600
Wavelength [nm]

Amplified spectra as a function of pump energy



Energy per pulse as a function of pump energy

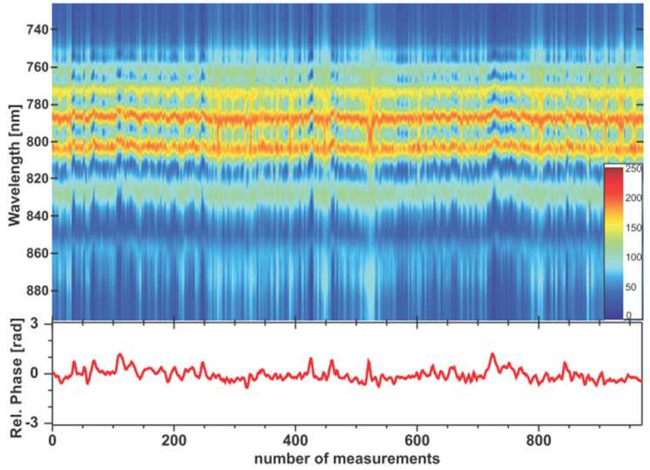




Seed Pulse

FOPA output

FOPA: 1.43 mJ



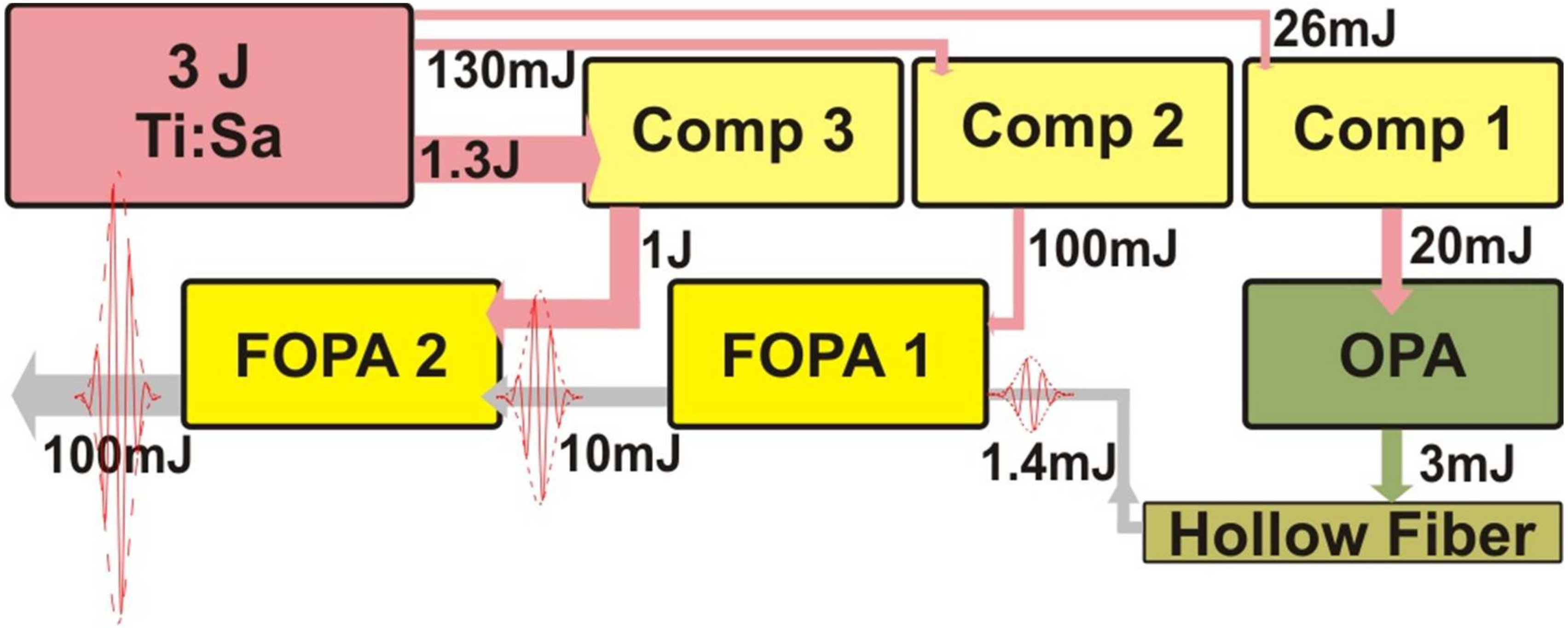
CEP stability at 50% amplification:
460 mrad measured over 1000sec,
each shot 10 times average
(350 mrad stability at input)

B. E. Schmidt et al. Nature Comm. **5**, doi:10.1038/ncomms4643.

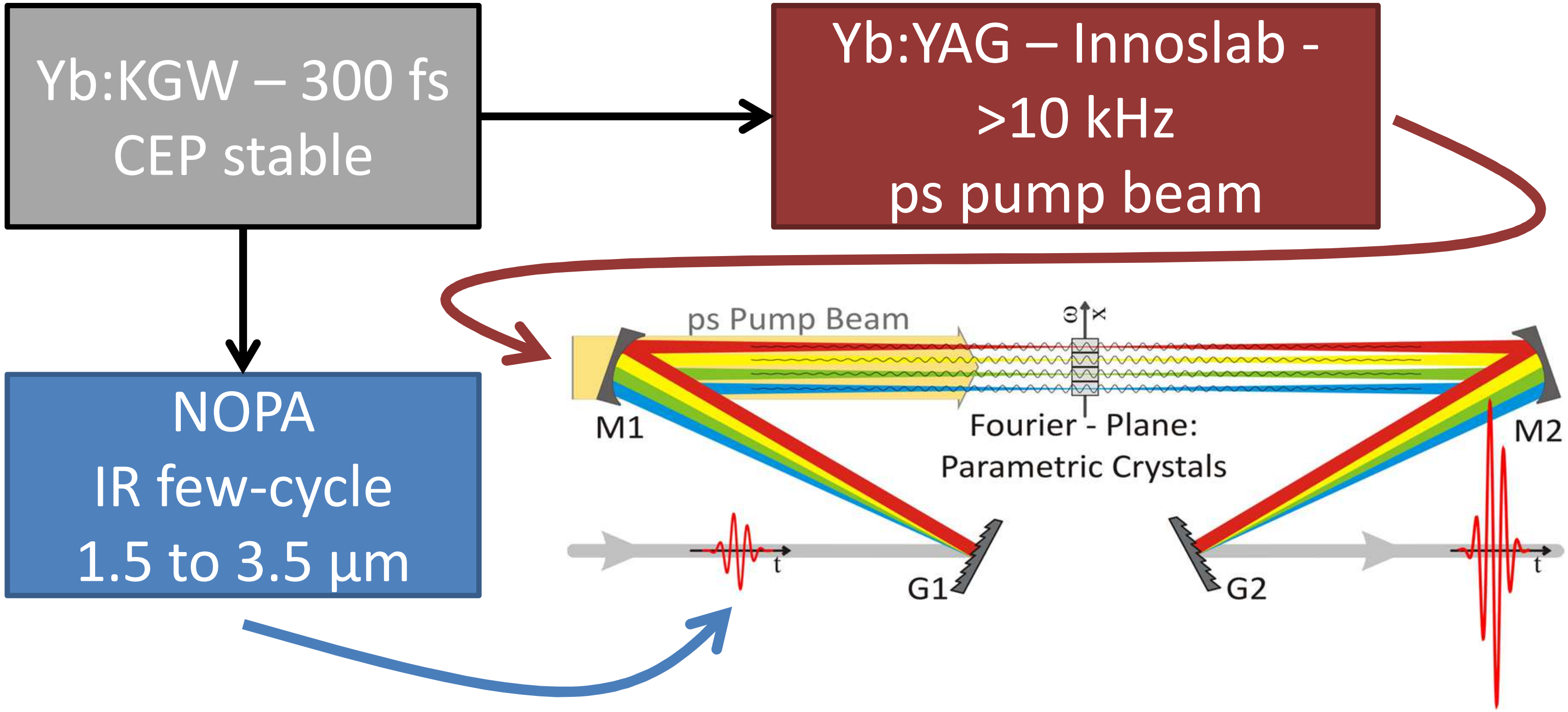
Advantages of FOPA

- Amplification of two cycle, 1.5mJ pulses
- Simultaneous upscaling of peak power and spectral bandwidth
- Upscaling not limited by aperture size of crystals
- No extra stretcher / compressor needed
- Absence of superfluorescence in the output beam
- No need for clean pump beam profile
- No Pulse Shaper for dispersion compensation
- Combination of many pump beams – no need for coherent synchronization.
- Amplification of arbitrary pulse shape possible

Short term plan – with Prof. Z. Chang



FOPA based on Yb (>10 kHz)



Yb:KGW – 300 fs
CEP stable

Yb:YAG – Innoslab -
>10 kHz
ps pump beam

NOPA
IR few-cycle
1.5 to 3.5 µm

- **Expected output:** 75 W at 1.5 µm, 35 W at 3.5 µm. Few-cycle pulses. CEP stability. FOPA based on KTA crystals.
- **Future:** Scaling the average/peak power by multiplexing pumping in the Fourier plane.

Thanks to the team

Fonds de recherche
Nature et
technologies
Québec

Conseil de recherches en sciences naturelles et en génie du Canada

Natural Sciences and Engineering Research Council of Canada

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ICIP
CIPI

ATTO 2015

5th International conference on Attosecond Physics

St-Sauveur, Qc, Canada, July 6-10

Tutorial speaker: Nirit Dudovich (Weizmann)

Invited speakers:
Hans Jakob Wörner (ETH)
Fernando Martin (UAM)
Kyung Taec Kim (GIST)
Tomoya Okino (RIKEN)
Oren Cohen (Technion)
Thomas Pfeifer (MPIK)
Zenghu Chang (UCF)
Jun Ye (JILA)

Chairs:
F. Légaré &
P. B. Corkum
legare@emt.inrs.ca

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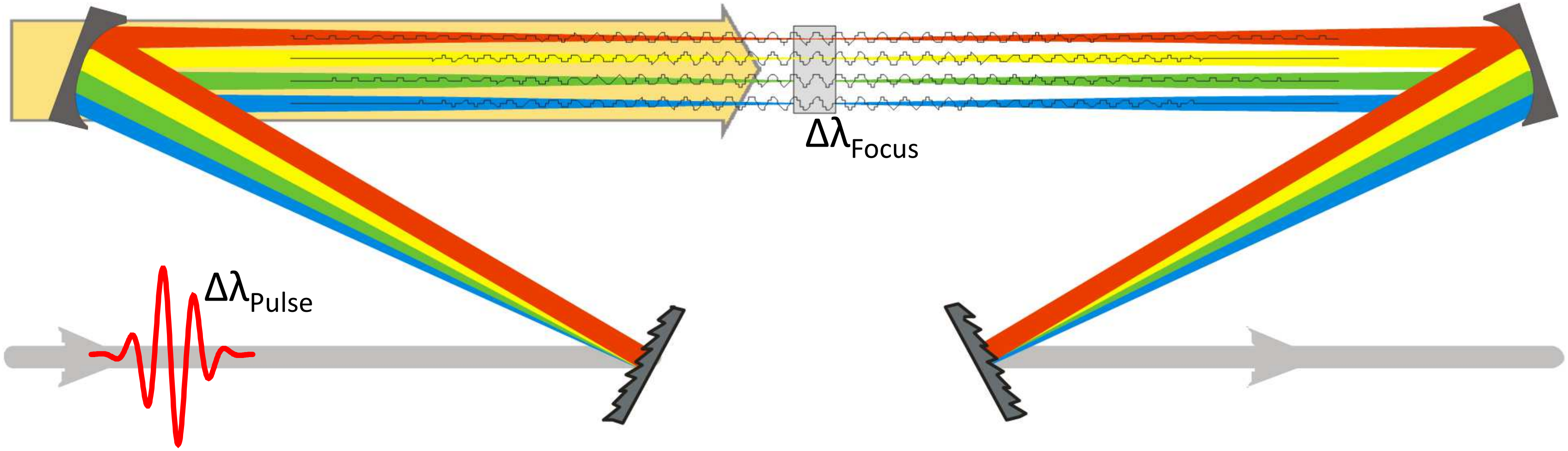
ALLS
Advanced Laser Light Source

NRC·CNRC uOttawa JASLab
Joint Laboratory for Attosecond Science Laboratoire commun de la science de l'attoseconde

Transform Limited seed Pulses

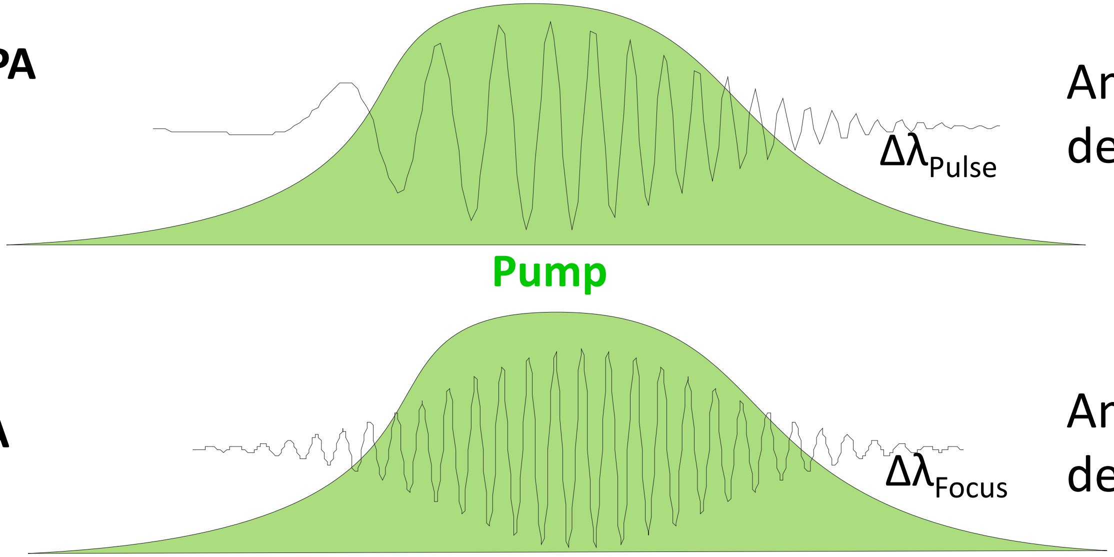


OPCPA

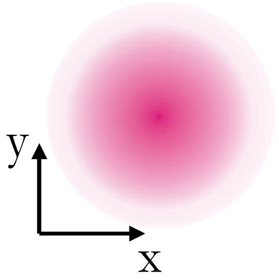
Amplified spectral bandwidth depends on pump duration

FOPA

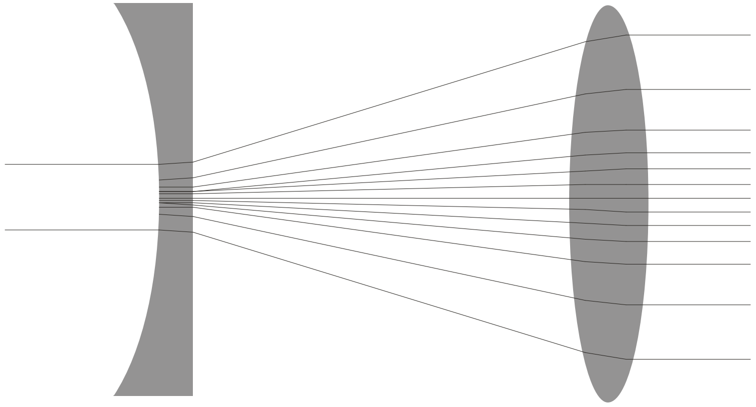
Amplified pulses are less dependent on pump duration



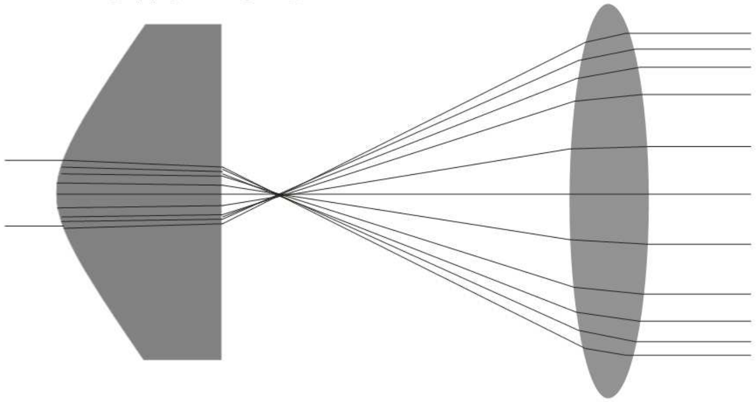
Gain Tailoring



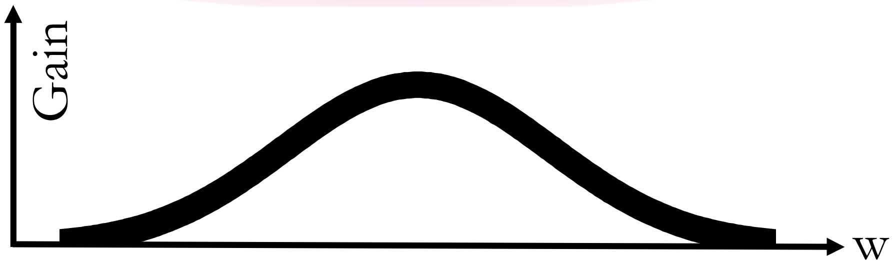
cylindrical lens



Powell lens



Gaussian



constant

wing enhanced