Sub-5-fs Multi-TW Optical Parametric Chirped Pulse Amplifier Development

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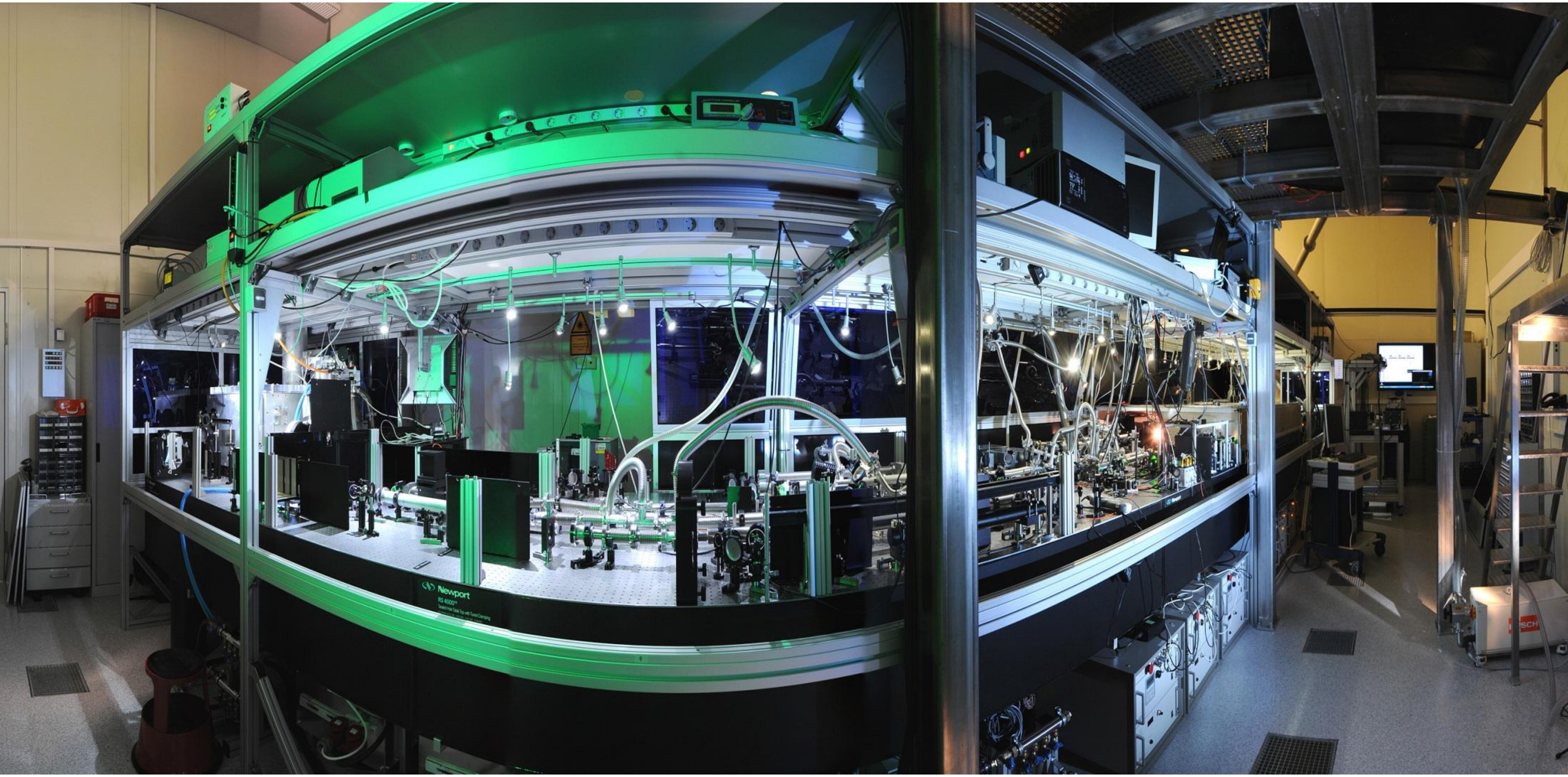

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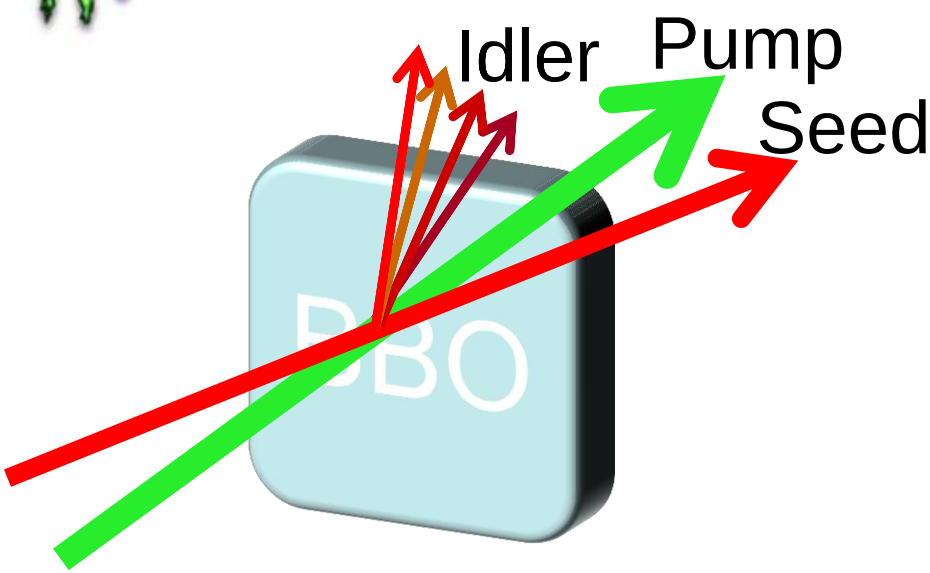
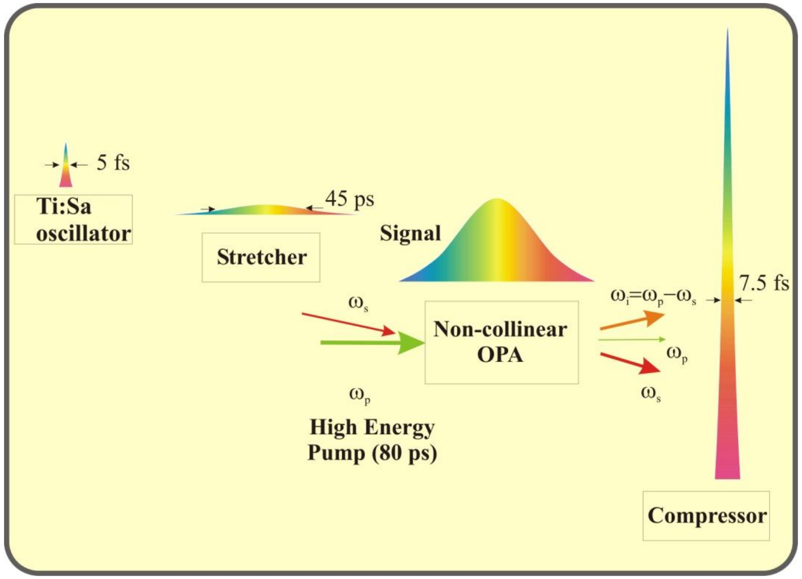
Outline

- Motivation for (few-cycle) optical parametric chirped pulse amplification (OPCPA)
- How to go to 5 fs pulse duration ? Optical parametric synthesizer
- Setup of Light Wave Synthesizer 20 (LWS-20)
- Dispersion management
- Spectrum and energy
- Compression and carrier envelope phase (CEP)
- Applications and summary

Noncollinear optical parametric chirped pulse amplification (NOPCPA)





Advantages

- <u>Broad gain bandwidth, supporting few-cycle pulses</u>
- Huge single pass gain (~10^6)
- No thermal load in the amplifier crystals
- <u>Good contrast achievable</u>

Challenges

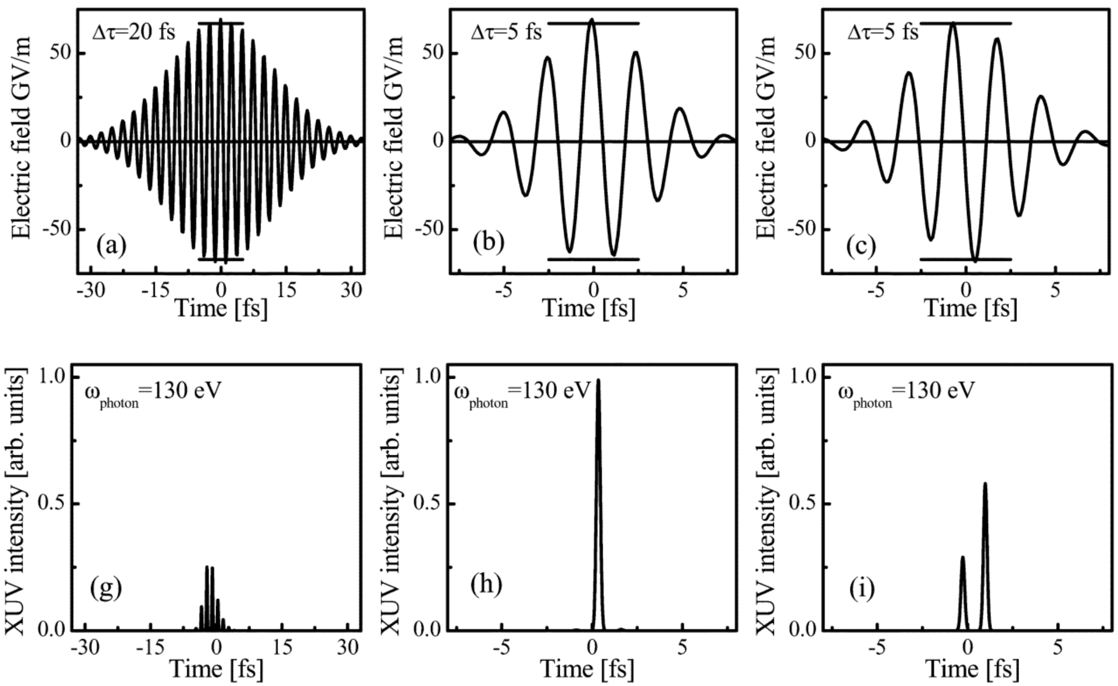
- Stretching and compression of huge spectral bandwidth
- Pump laser
- Synchronization of pump and seed
- Amplification of the optical parametric fluorescence (superfluorescence)
- Carrier envelope phase stabilization

Why to go to 5 fs ?

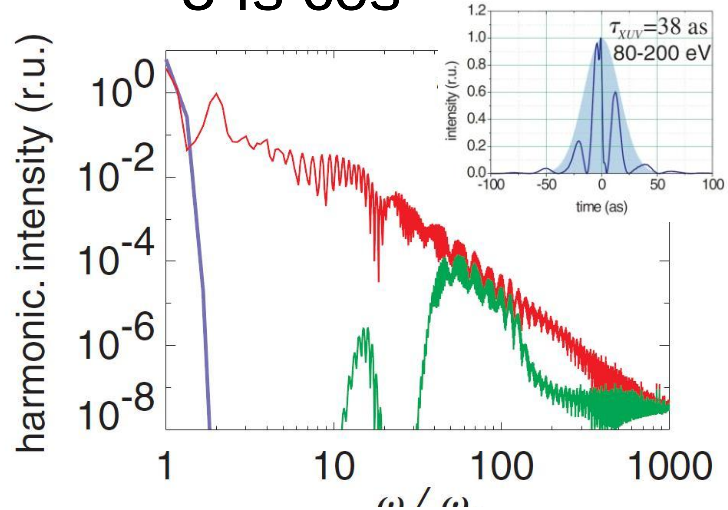
Generation of single attosecond light and electron pulses in gas and plasma medium

Gas harmonics

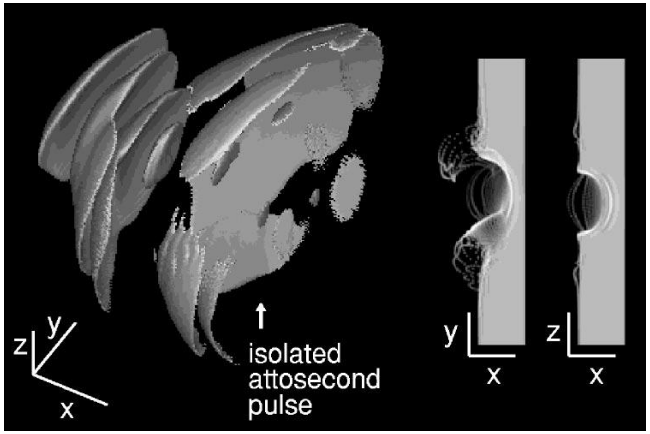
20 fs | 5 fs cos | 5 fs sin



Surface HHG
5 fs cos



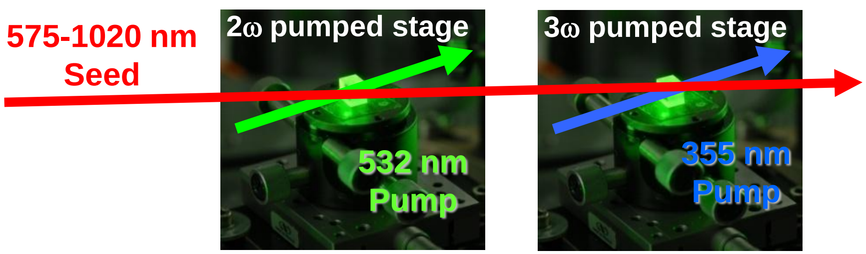
λ^3 regime

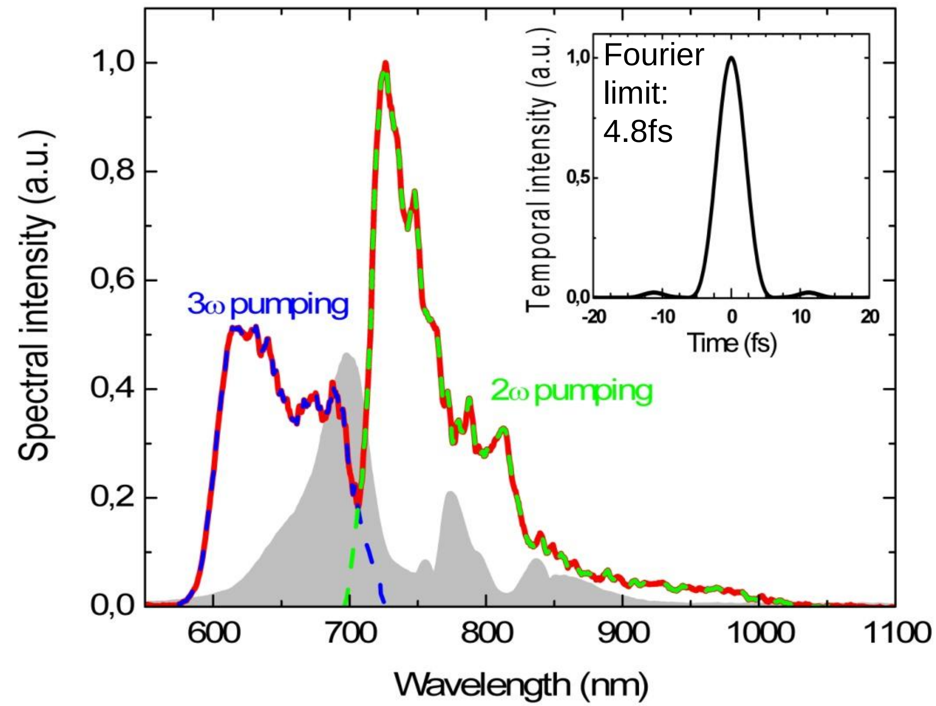


G. D. Tsakiris et al., New J. Phys. 8, 19 (2006)
N. M.Naumova et al., Phys. Plas. 12, 056707 (2005)
A. Baltuska et al., IEEE J. of Sel. Top. in Quantum Electronics 9, 972 (2003)

How to generate 5 fs ?
Optical parametric synthesizer

Two-colour pumping+ – with the **2ω** and **3ω** of the pump fundamental in two different NOPCPA stages



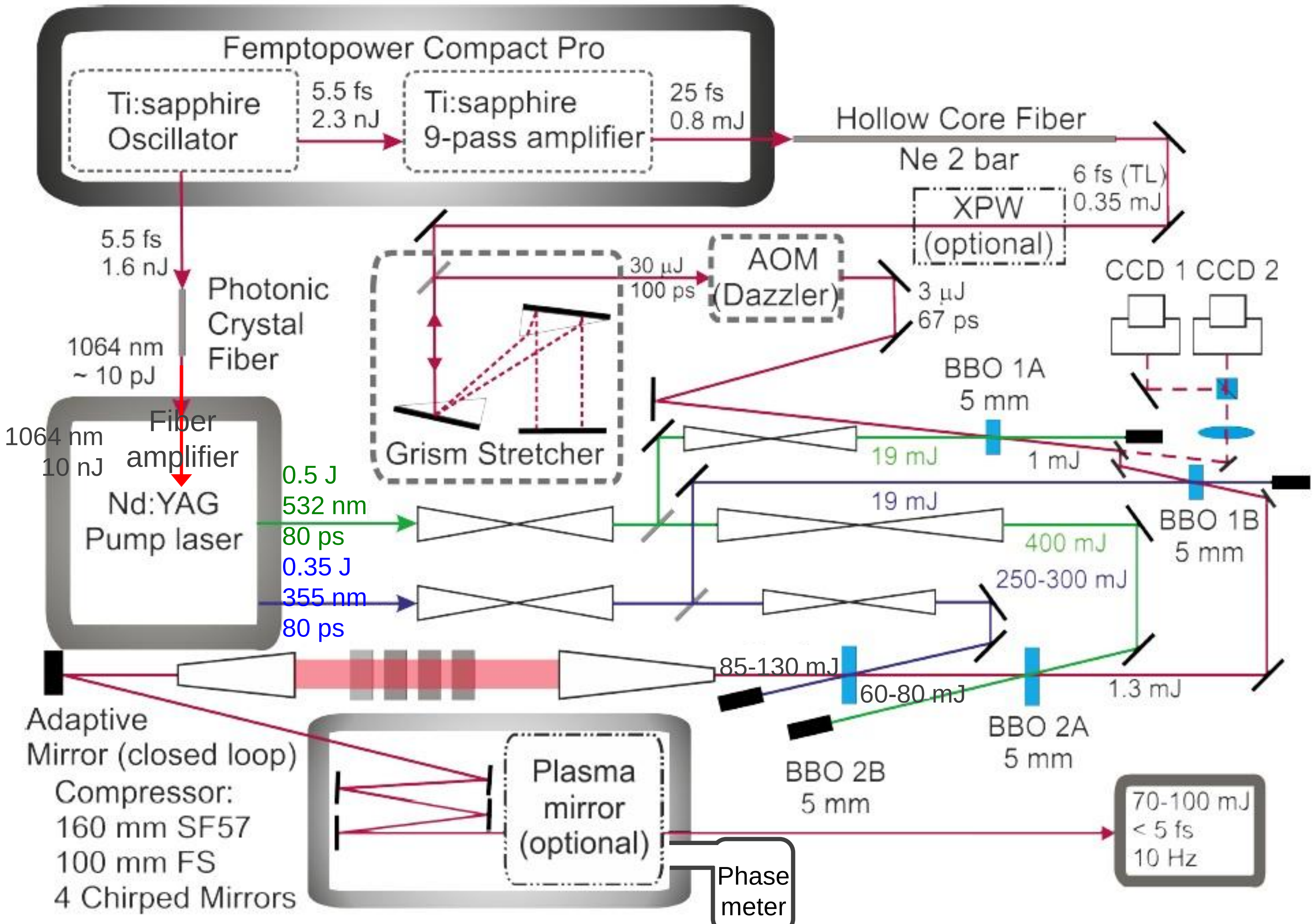


Advantages:

Even broader spectrum (575-1020 nm)
Even shorter (sub-two cycle) pulses (Fourier limit 4.8 fs)
Relative simple realization with the same pump laser

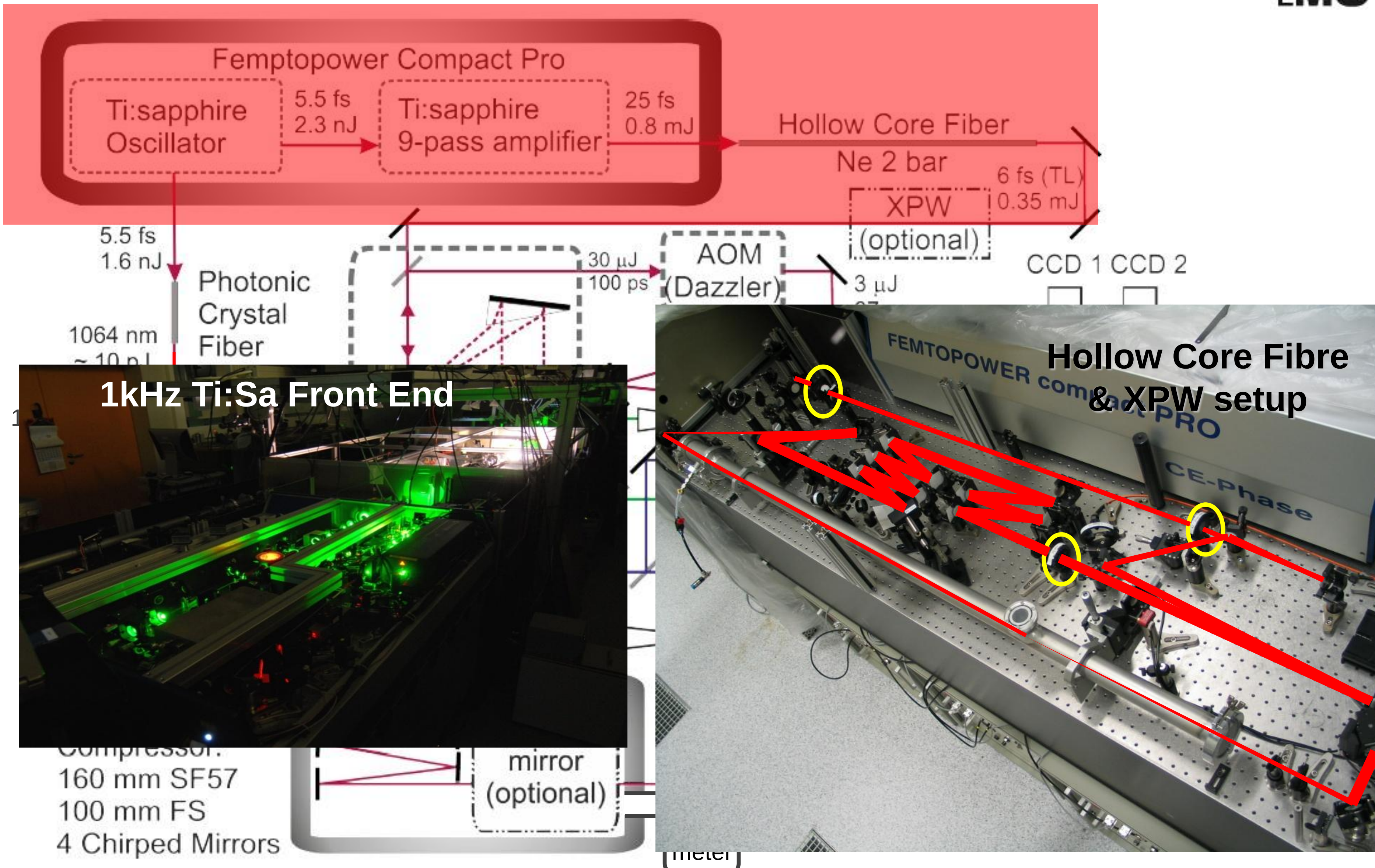
+ D. Herrmann *et al.*, *Opt. Exp.* **18**, p. 18752 (2010)

Setup for the 5 fs LWS-20



Front end & hollow core fiber

MPQ LMU www.attoworld.de



Dispersion management

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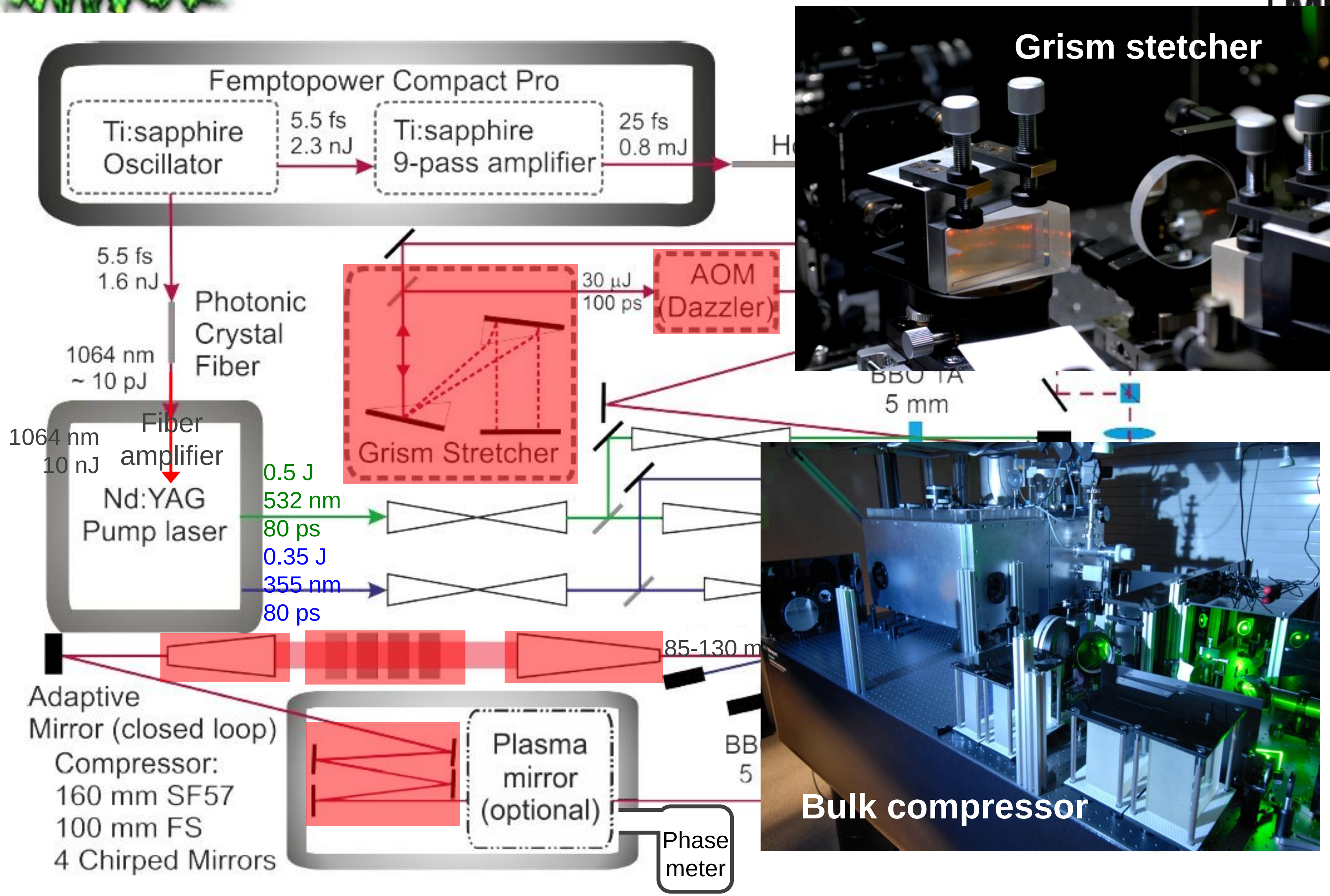
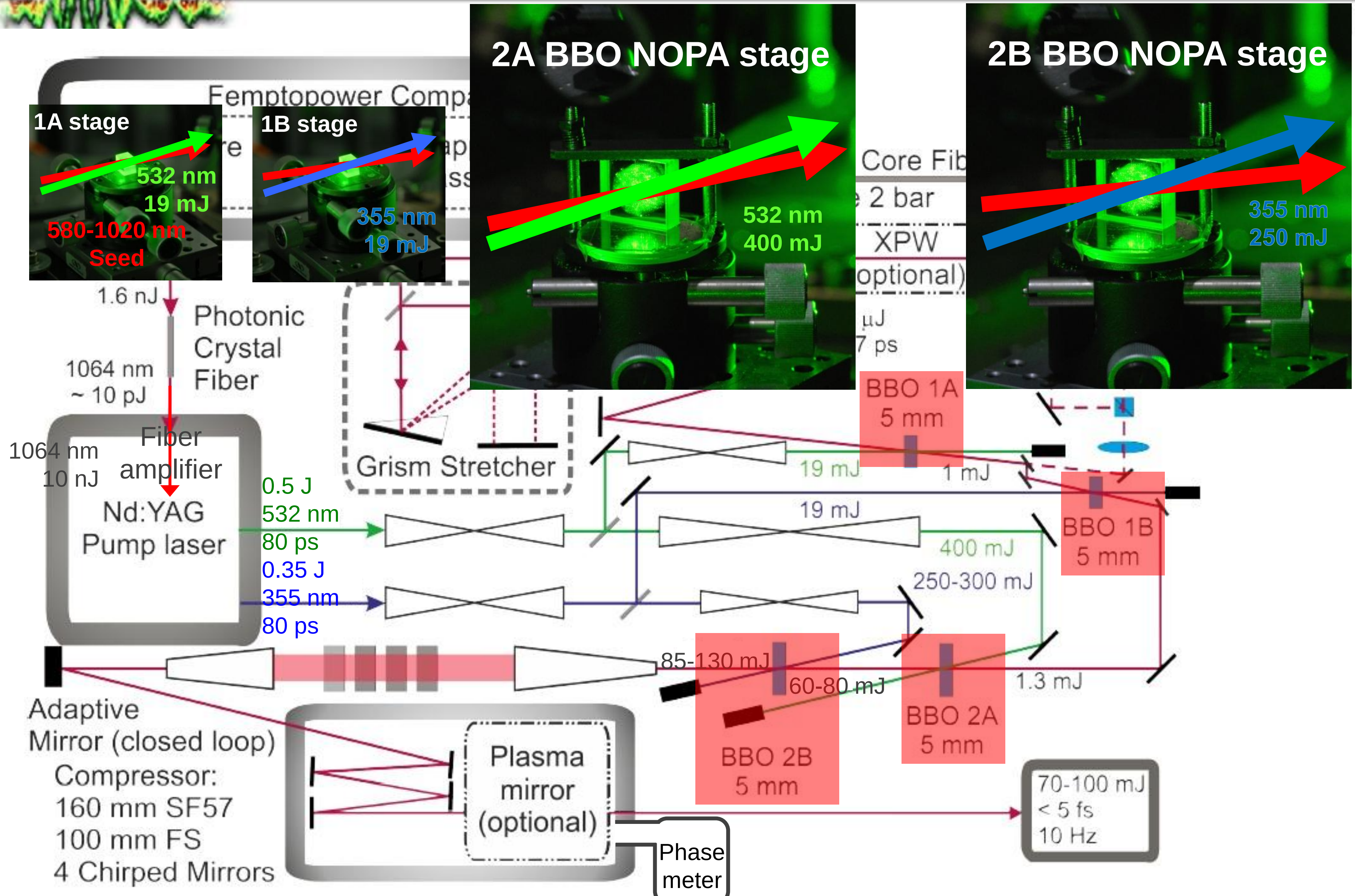


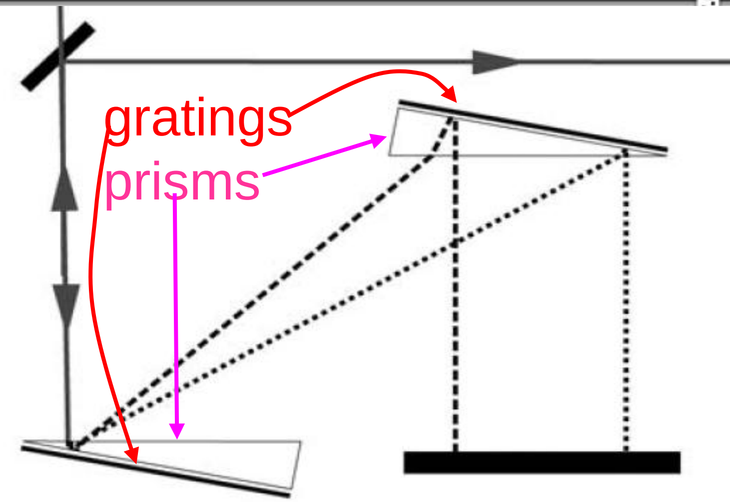
Four NOPCPA stages



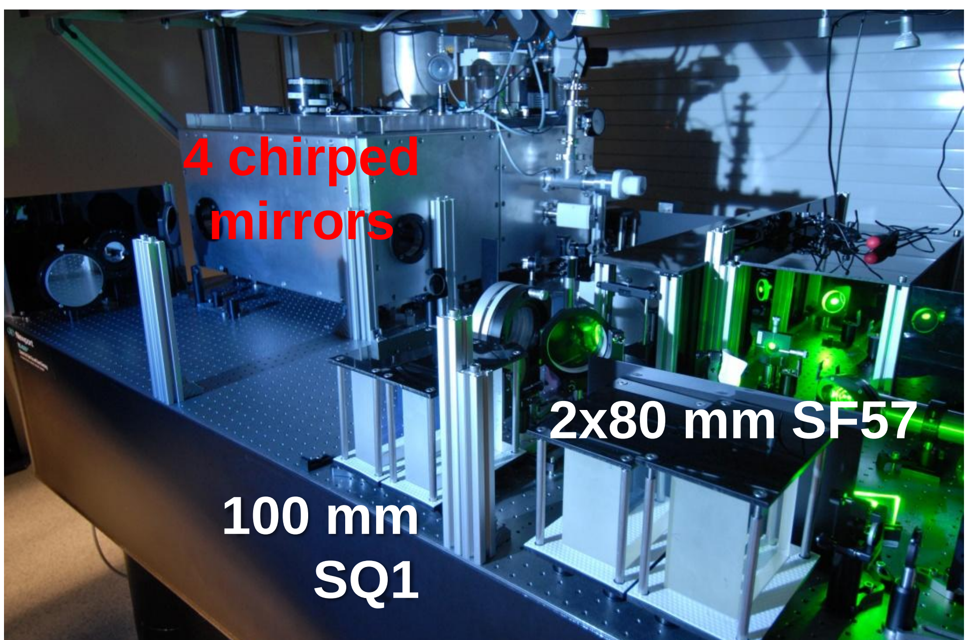
Dispersion management

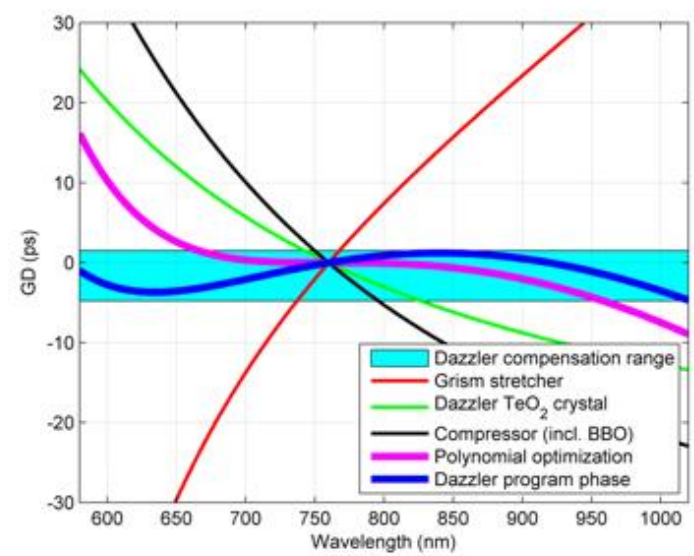
Conventional grating compressor
with LWS-20 bandwidth has **T=50% !!!**

- → High transmission compressor is necessary!
- → Bulk glass & chirped mirror compressor **T=80%**
- → Special design results in stretching with **100 ps group delay** between 580 - 1020 nm



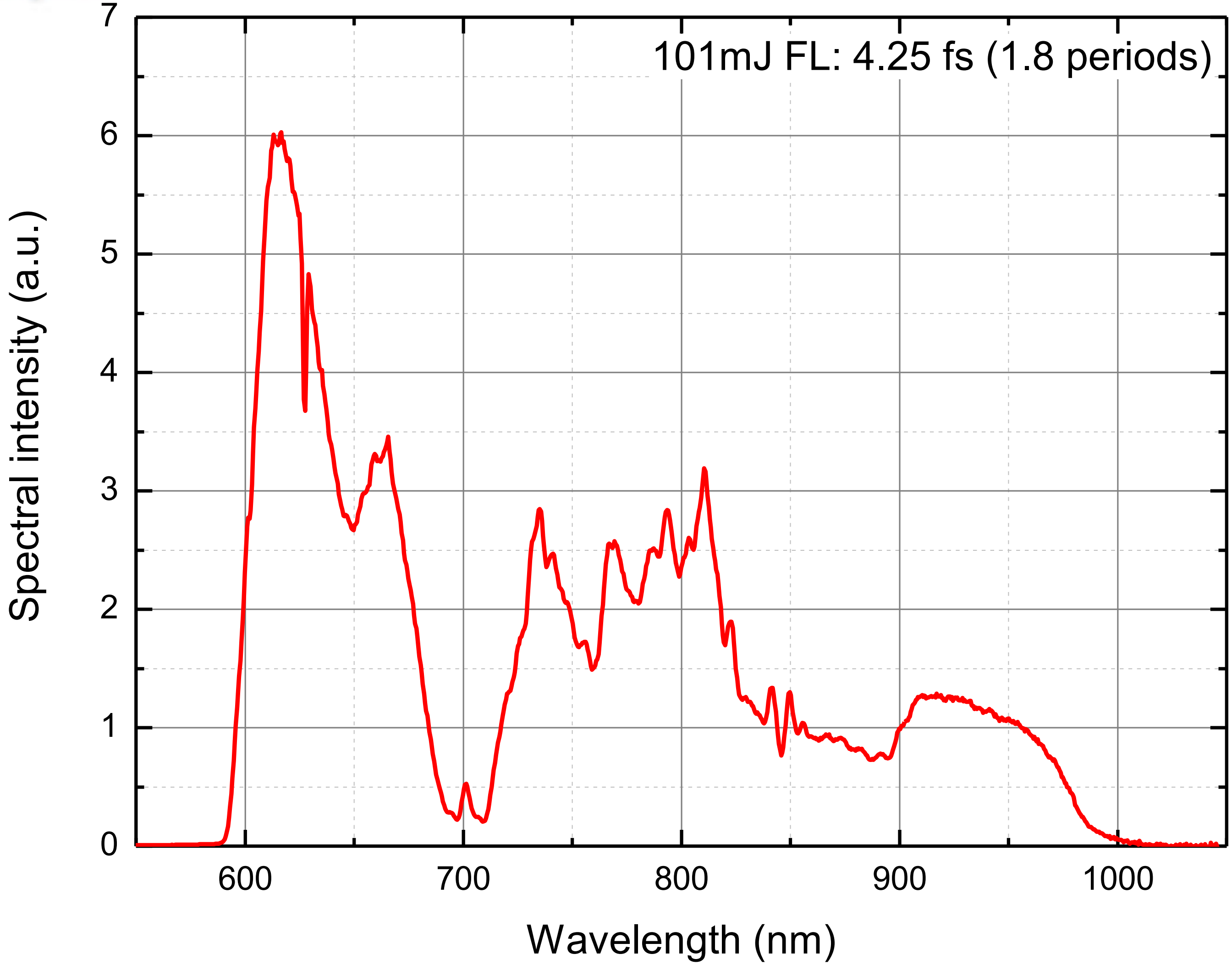
grism stretcher





T. H. Dou *et al.*, *Opt. Exp.* **18**, p. 27900 (2010)

First spectrum of 5 fs LWS-20



Generation of even shorter than 5 fs / 2 cycle pulses is feasible!

Principle of optical parametric synthesizer

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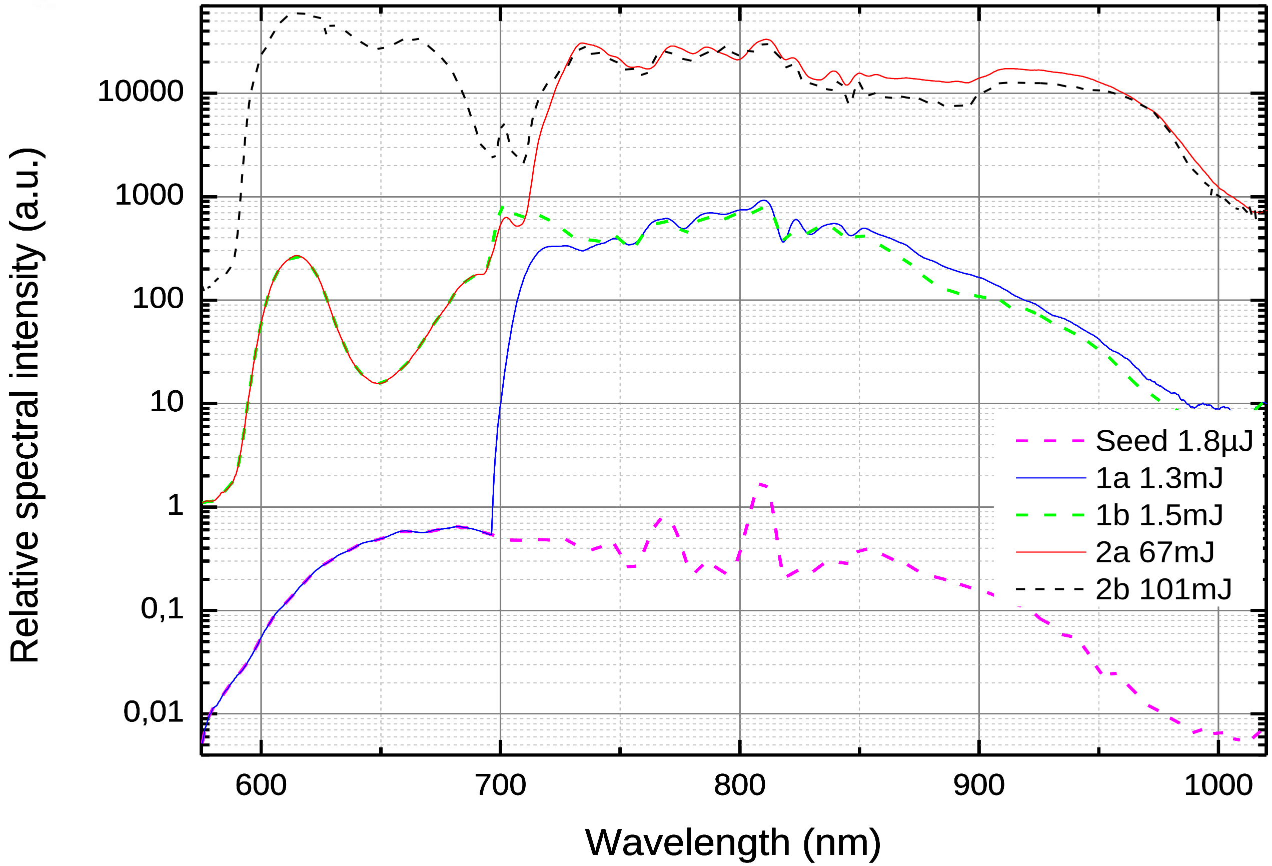
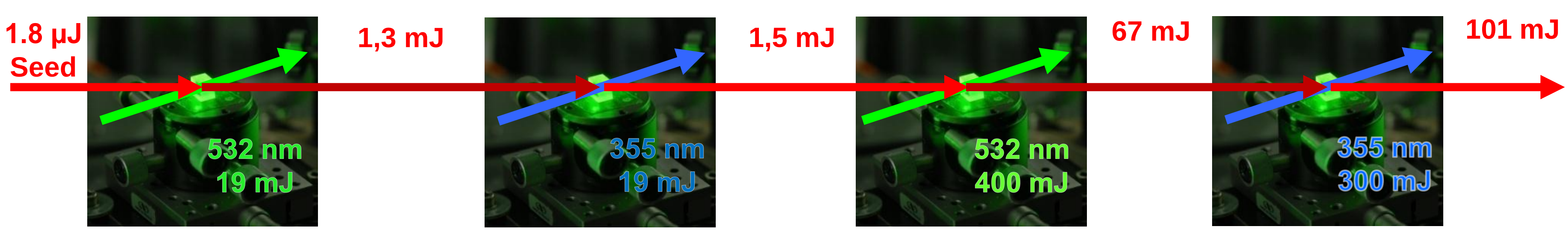
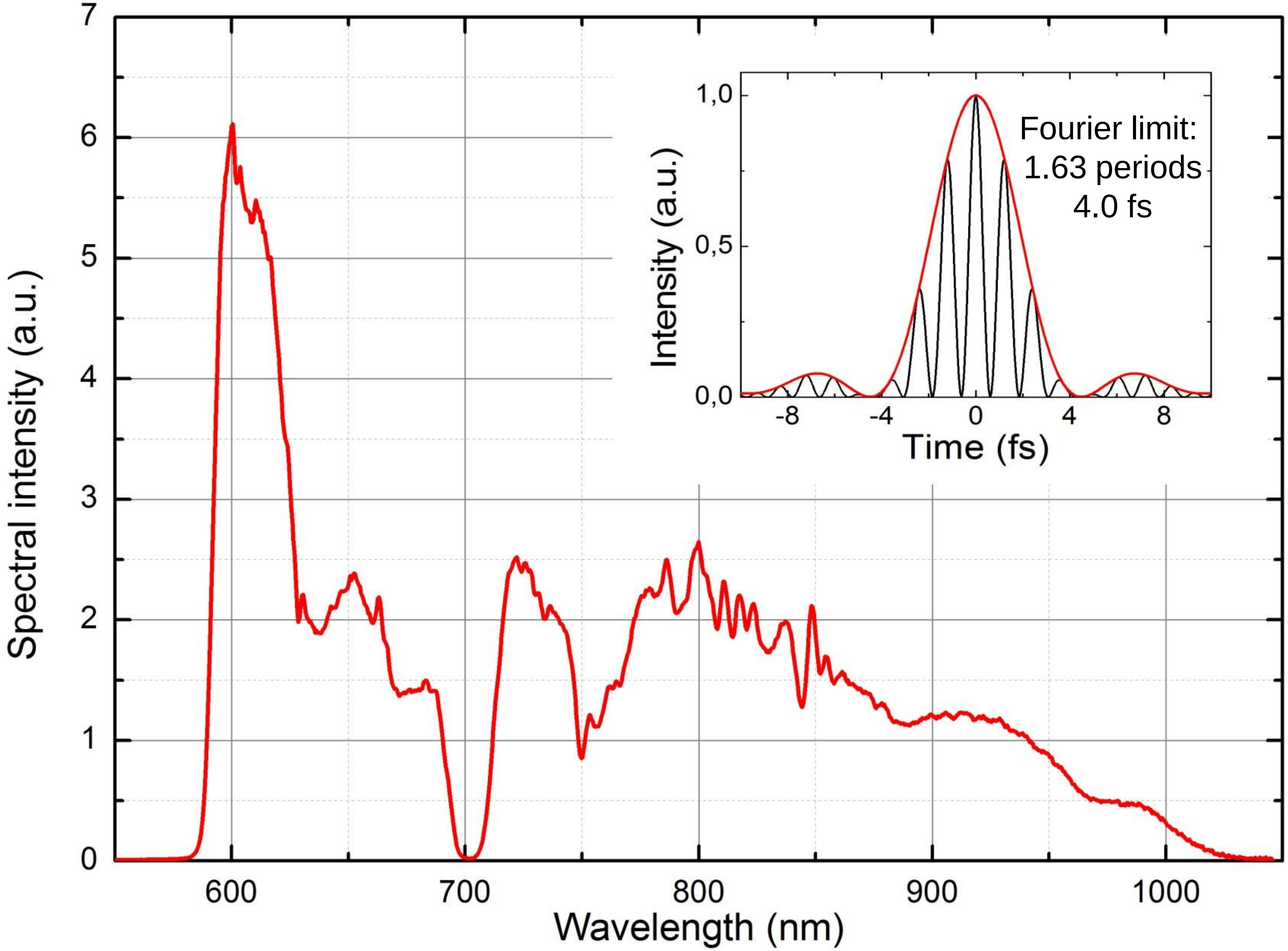




Broad spectrum of 5 fs LWS-20



Energy: 100 mJ before compression, possible improvement towards 140 mJ
~80 mJ after compression

Compression 1

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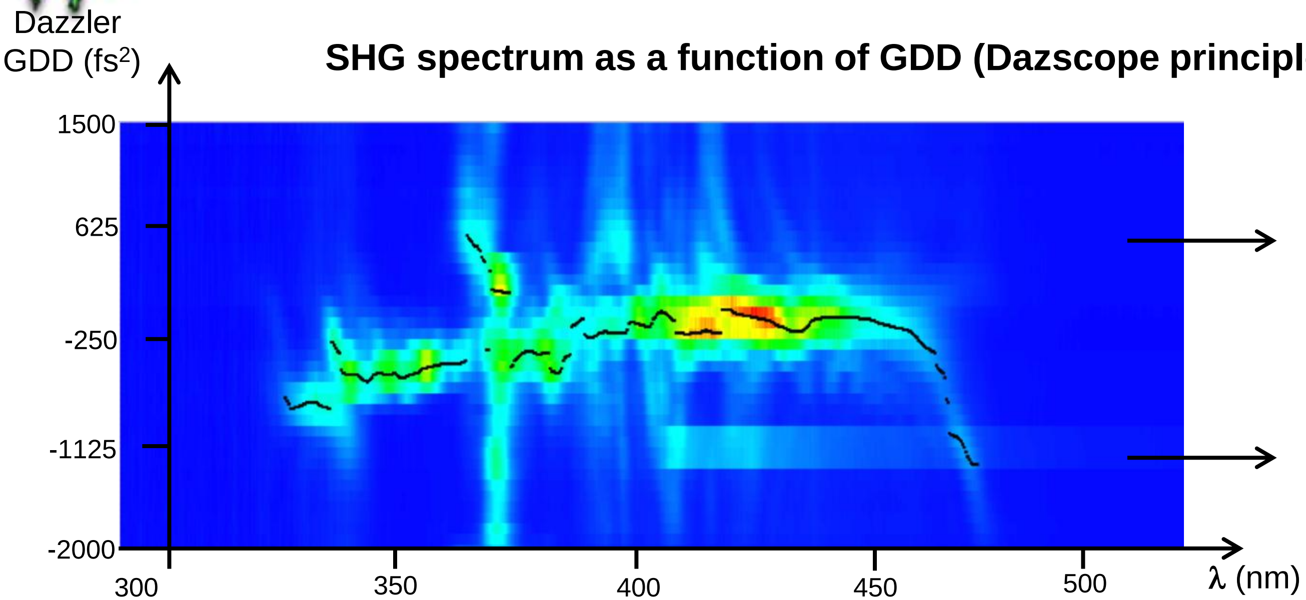
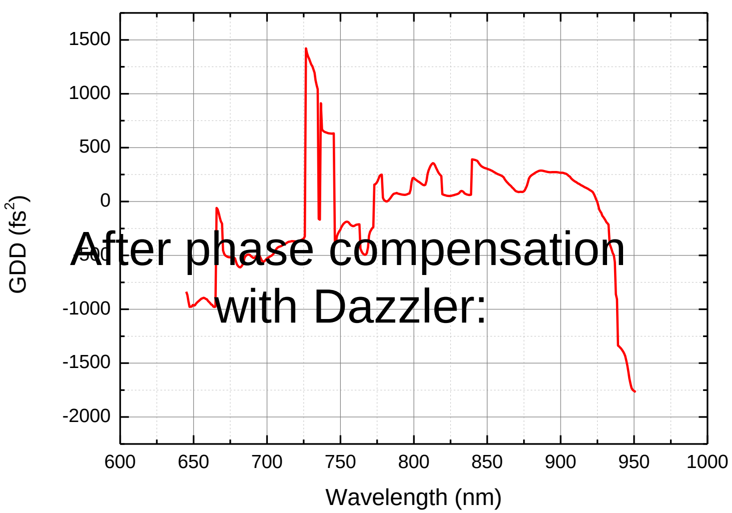
SHG spectrum as a function of GDD (Dazscope principle)

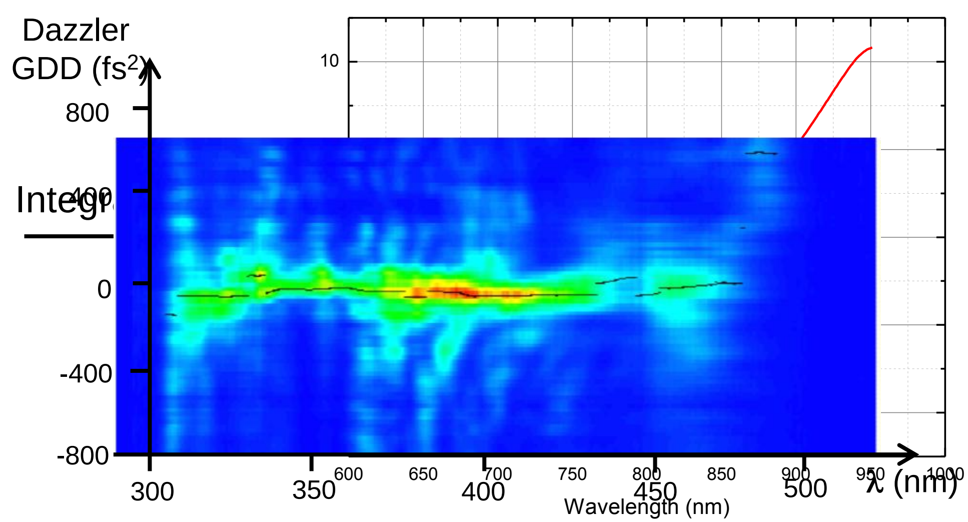


GDD scan using Dazzler.

Highest intensity at λ corresponds to total GDD(λ) = 0

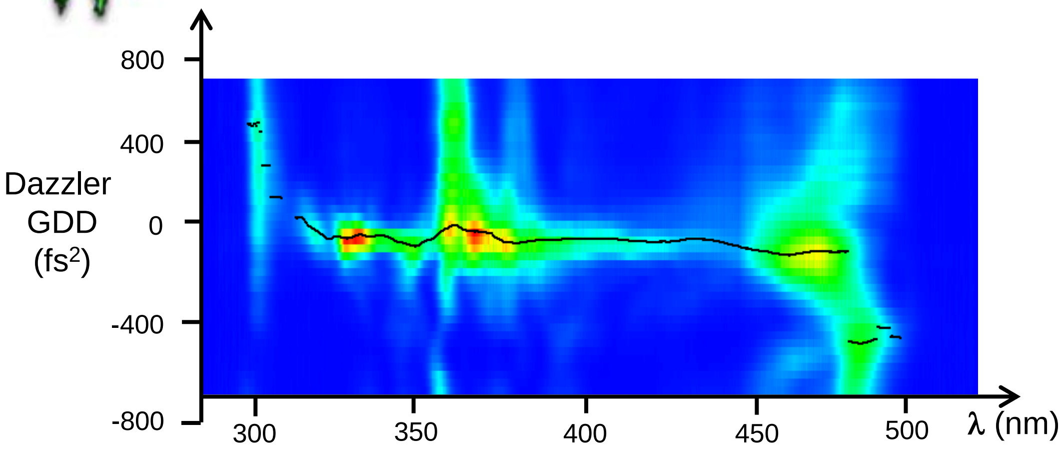


After phase compensation with Dazzler:



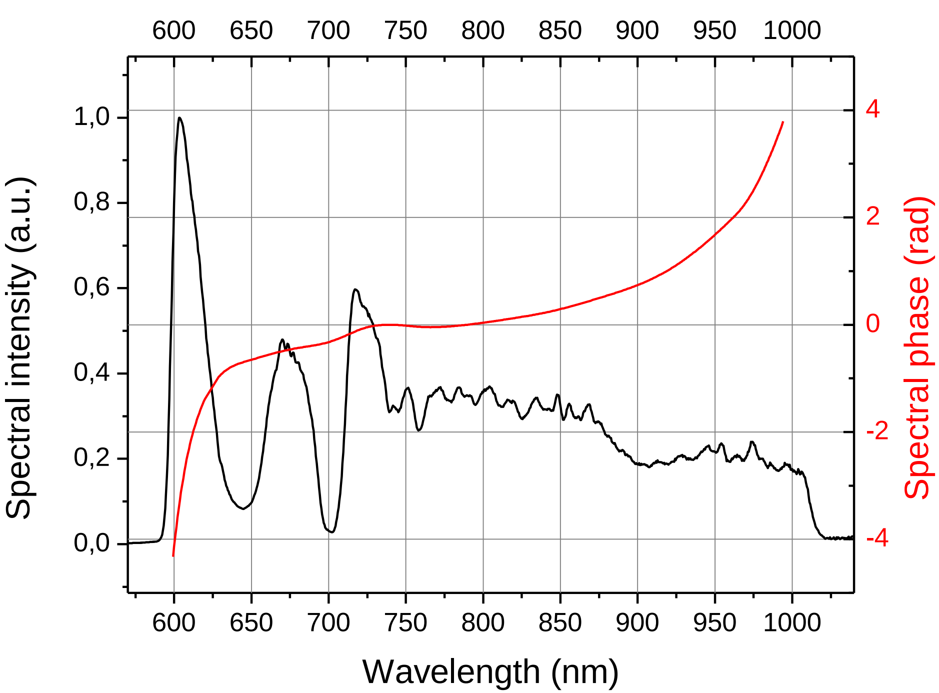
Integr

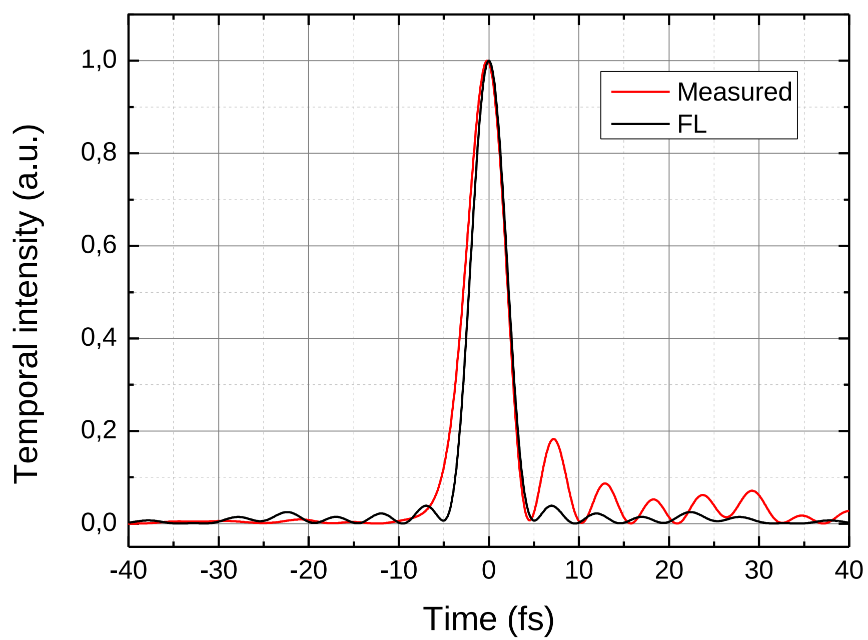
Compression 2



Single shot Dazscope evaluation

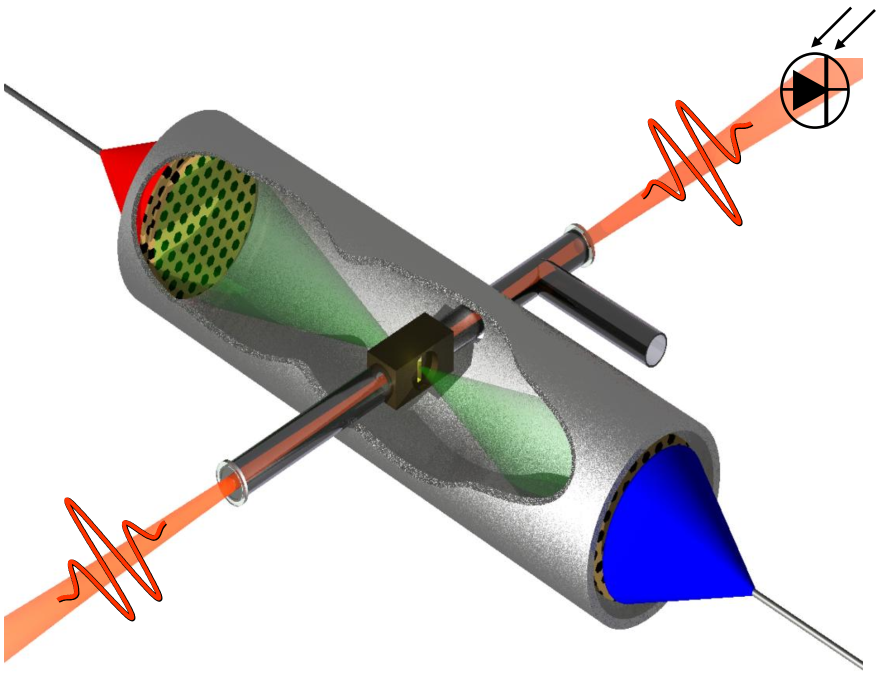
FWHM Fourier limit: 4.4 fs
FWHM pulse duration: 4.9 fs



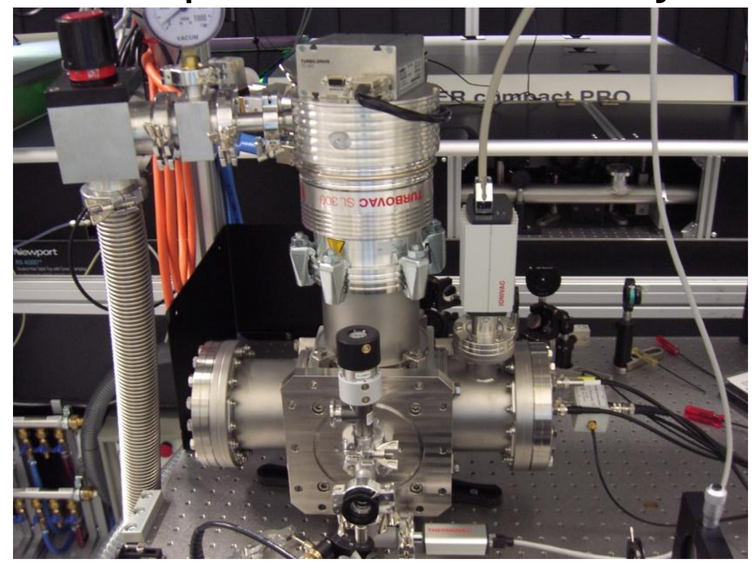


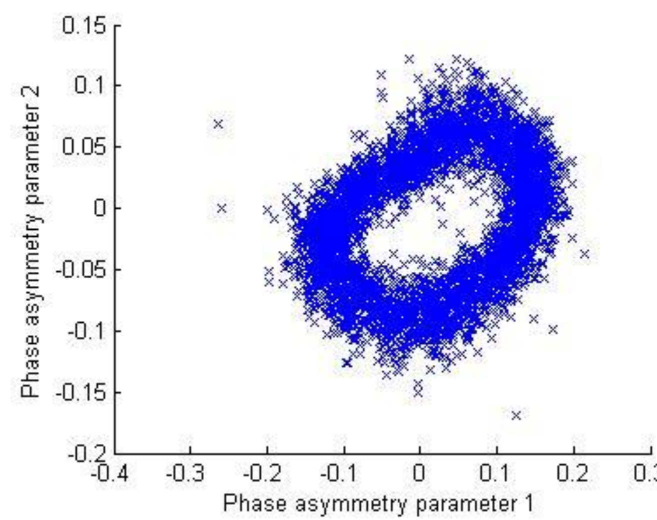
Carrier envelope phase (CEP) meter

Single shot CEP tagging is crucial!



A new phase meter is ready.

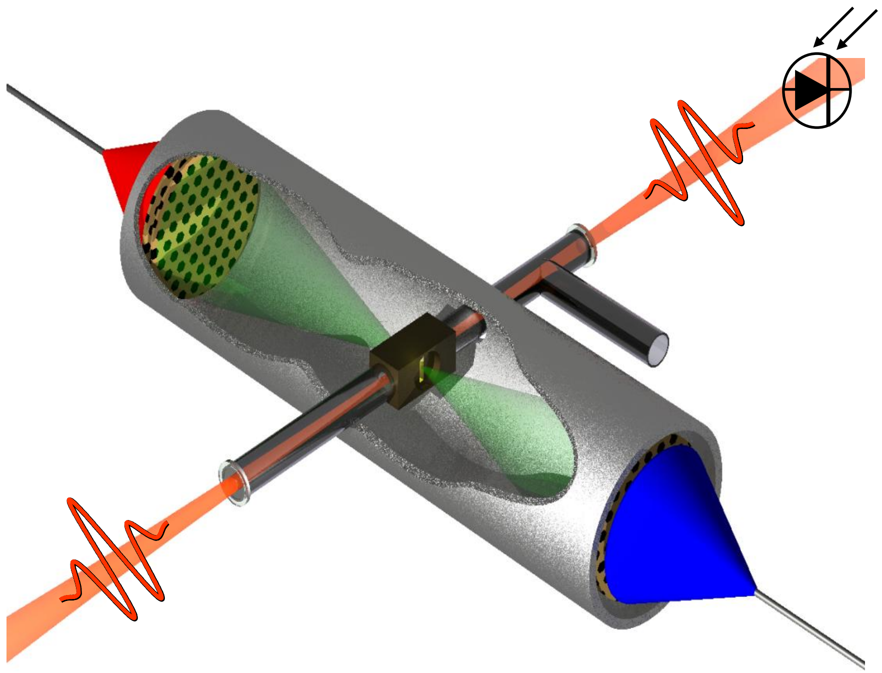




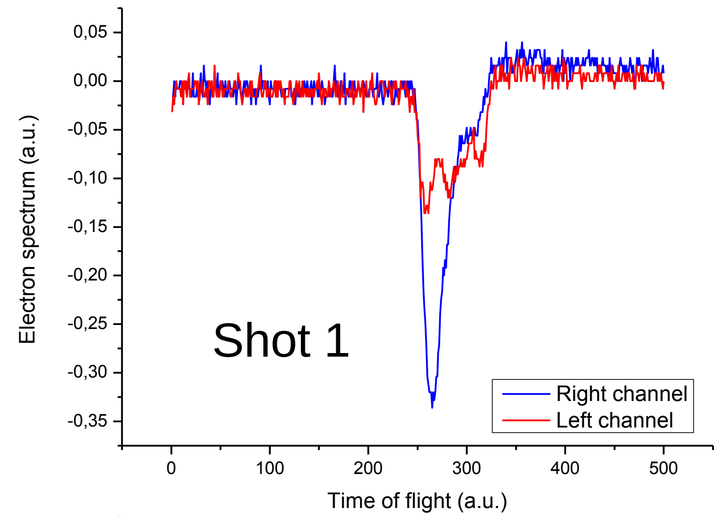
T. Wittmann et al., Nature Phys. **5**, 357 (2009)

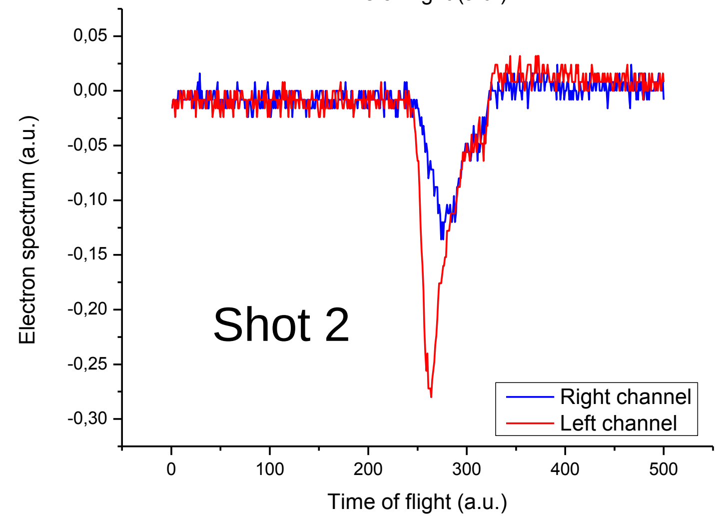
First single shot CEP results

SS CEP meter is implemented



Raw single shot CEP meter spectra using LWS-20:





T. Wittmann et al., Nature Phys. **5**, 357 (2009)

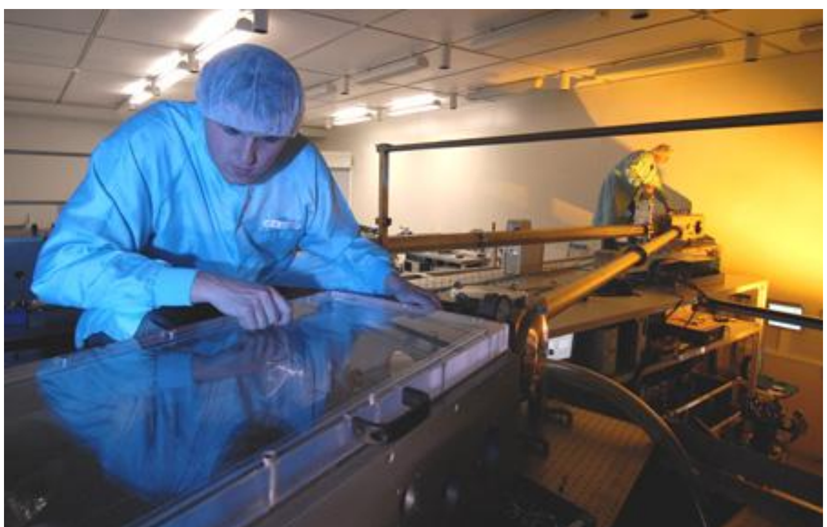
Applications

High harmonic generation from gas targets

– Single attosecond pulse generation in gases

– (few-)100-as pulse duration

– up to 1 µJ in attosecond pulse with LWS20 + QPM

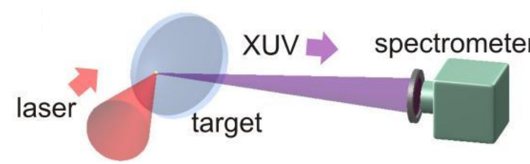


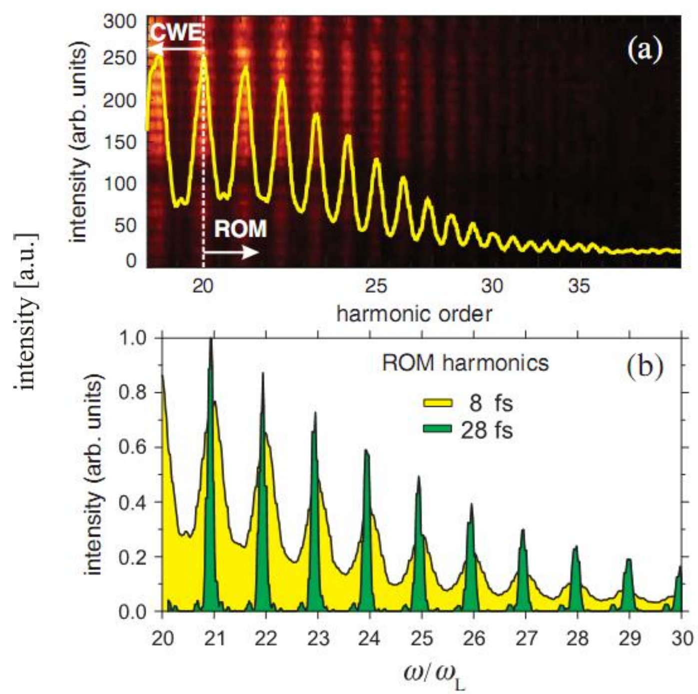
Surface high harmonic generation

– Generation of high harmonics in plasmas

– Shorter attosecond pulses

– 100 µJ – 1 mJ energy in attosecond pulse





***Open up a new era of XUV pump – XUV probe* experiments with single attosecond pulses!**

Further goals

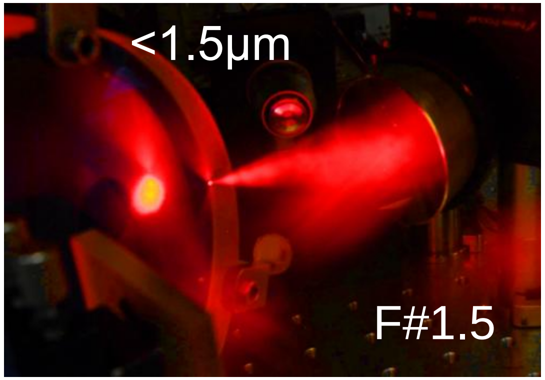
- Upgrade step I:
  Bandwidth increase to reach
  ~5 fs pulse duration

- Single shot CEP-measurement /
  stabilization of the OPCPA system

LWS-20
80-100 mJ, 5 fs, 16 TW
CEP tagged OPCPA system

- Upgrade step II:
  Pump laser energy upgrade
  4 x more energy with 80 ps,
  10 Hz is delivered

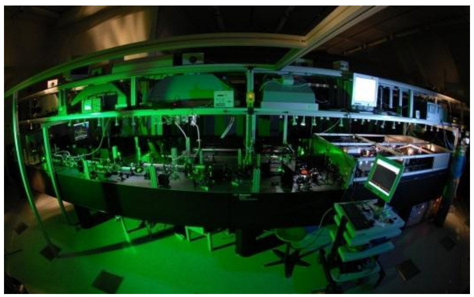
Future upgrade goal: LWS-100
300-500 mJ, 5 fs, 60-100 TW

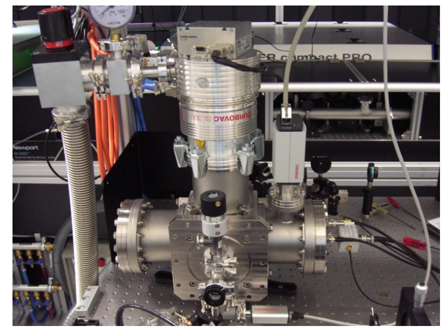


- 1st step towards generation of intense
single attosecond light and electron pulses:
Focusing with F#1.5 spot size <1.5 µm → I>10^{20}W/cm^2

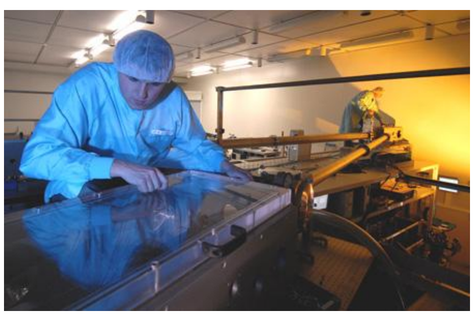
Summary

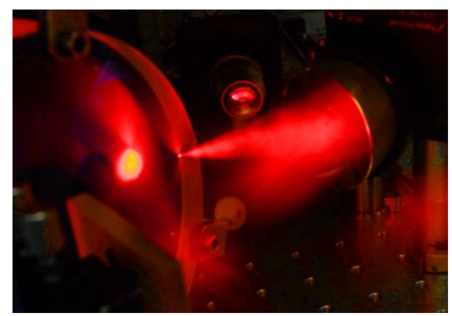
o LWS-20 upgrade 80-100 mJ, 5 fs, CEP tagging is ready





o Applications of LWS-20 are ready to start





o Upgrade towards ~100 TW is planned

Thank you for your attention !

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