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Front-End of Yb-based High-Energy Optical Waveform Synthesizer

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Motivation

- **Challenge 1:** Generation of Isolated Attosecond-pulse
  - Solutions:
    - Using gating techniques:
      - Polarization gating
      - Double-optical gating
      - Ionization gating
      - Two-color driving
    - Using single or sub-cycle driver pulses

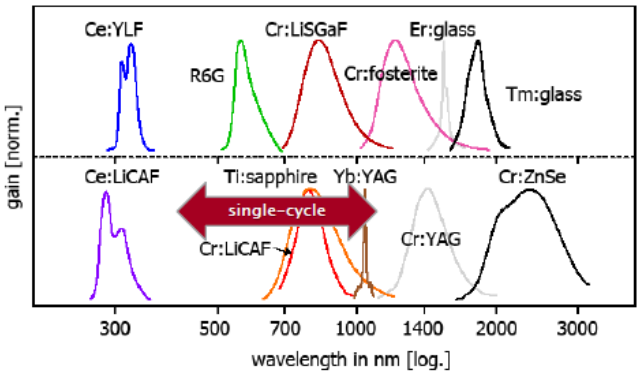
- **Challenge 2:** Improvement of efficiency
  - Optical efficiency is on the order of 10^{-5-7}
  - Solution: Phase matching optimization and short-wavelength driver laser

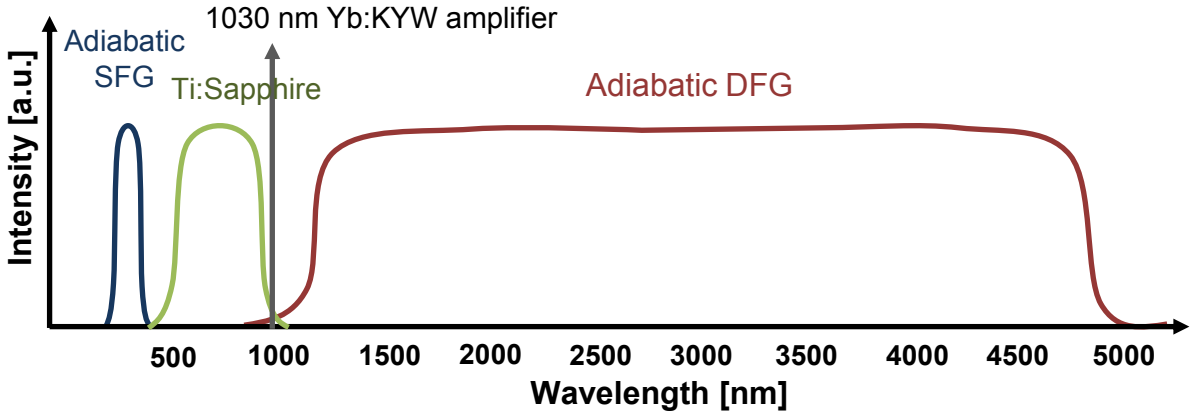
- **Challenge 3:** Extend x-ray cut-off
  - Generation of x-ray in water window.
  - Solution: Long-wavelength driver laser

[1] G. Sansone, et al., Science 314(5798), 443–446 (2006).
[2] H. Mashiko, et al. Phys. Rev. Lett. 100(10), 103906 (2008)
[3] M. J. Abel, et al. Chem. Phys. 366(1-3), 9–14 (2009).
[4] B. Kim, et al. Opt. Express 16(14), 10331–10340 (2008).
[5] Chipperfield et al., PRL 102, 063003 (2009)

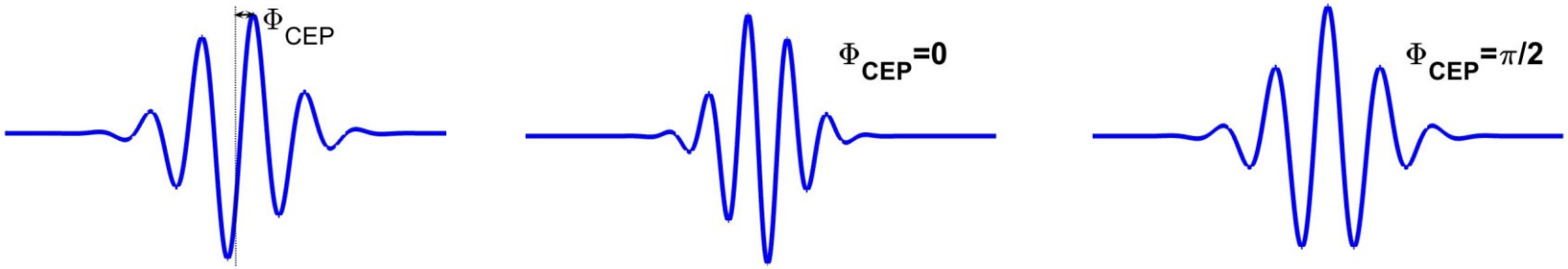
Driver Laser Requirements

- Broadband laser pulses supporting single or sub-cycle pulses





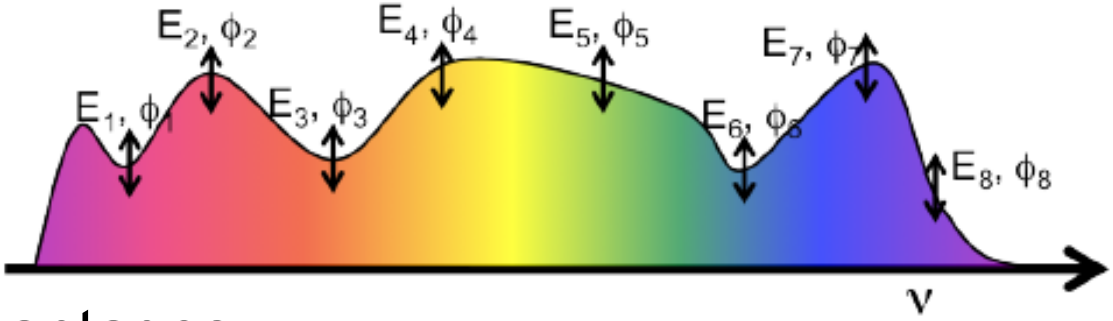
- High energy pulses
- Carrier-envelope phase stability



Suggested Laser Source

- Optical Wave Parametric Synthesizer
  - Generation of broadband seed source
  - Amplify different spectral regions separately in a optical parametric amplifier
  - Combine and compress

Adjustment of timing in sub-cycle time duration
Control of relative phase

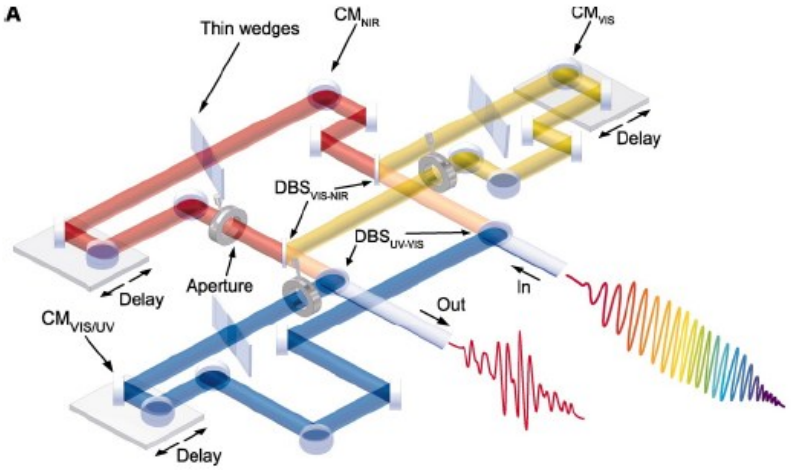


- Advantages
  - Energy scalability
  - Spectral scalability
  - Control in electric field of the driver laser

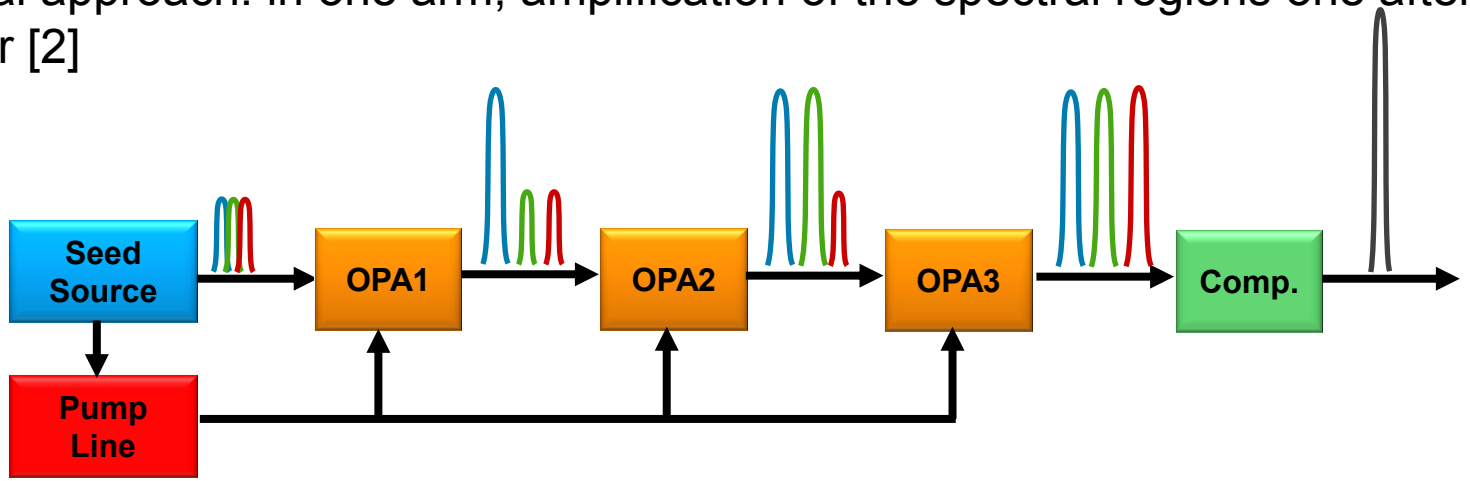
[1] Chipperfield et al., PRL 102, 063003 (2009)
[2] E. Balogh, et al., PRA **90**, 023855, (2014)

Previous works

- mJ pulses compressed in hollow core fibers from sub-50 fs to few-cycle duration [1]



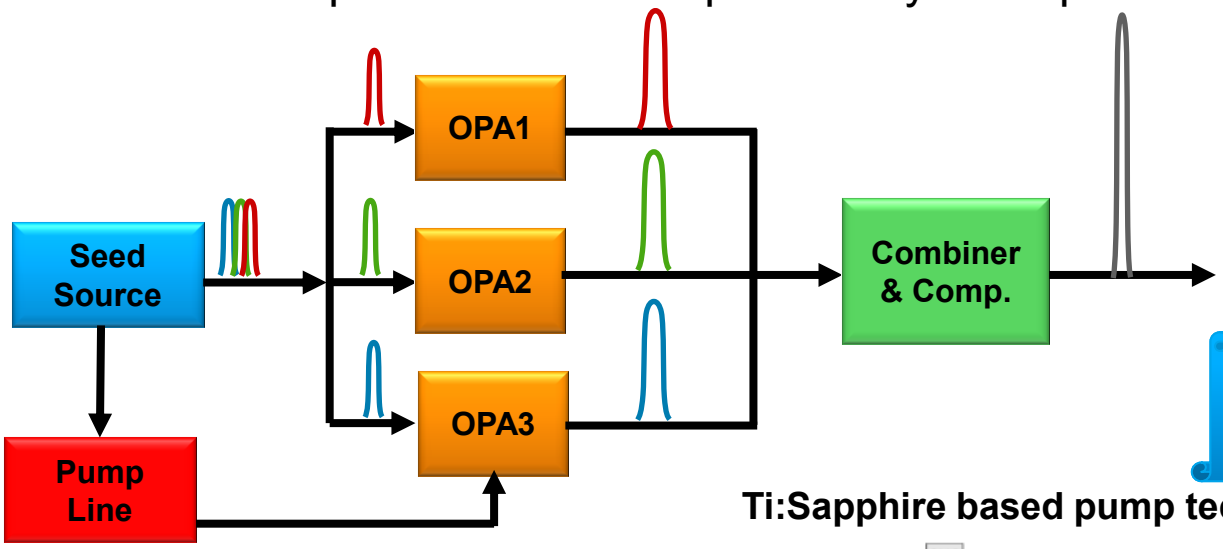
- Serial approach: in one arm, amplification of the spectral regions one after each other [2]

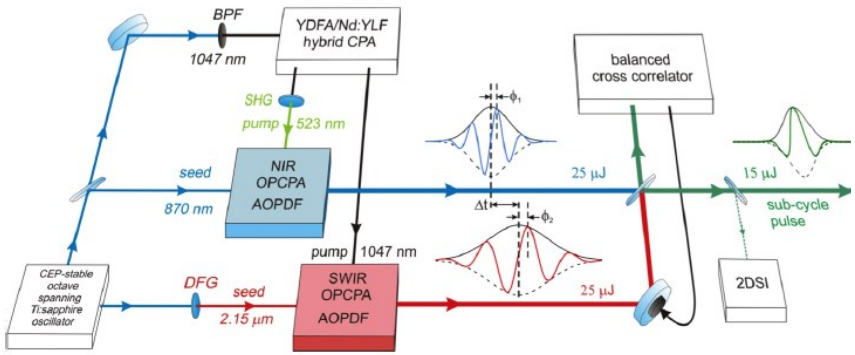


[1] Wirth et al., Science **34**, 195, (2011)
[2] Harth et al., OE **20**, 3076, (2012)

Previous works

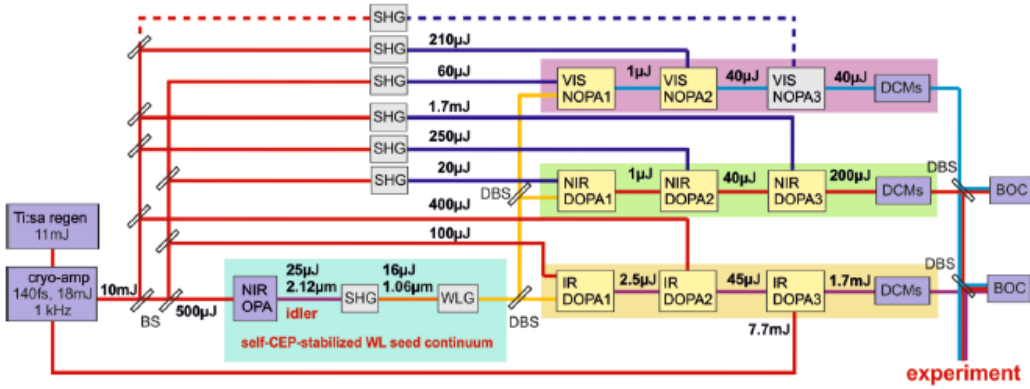
Parallel approach: each amplification arm amplifies only one spectral region





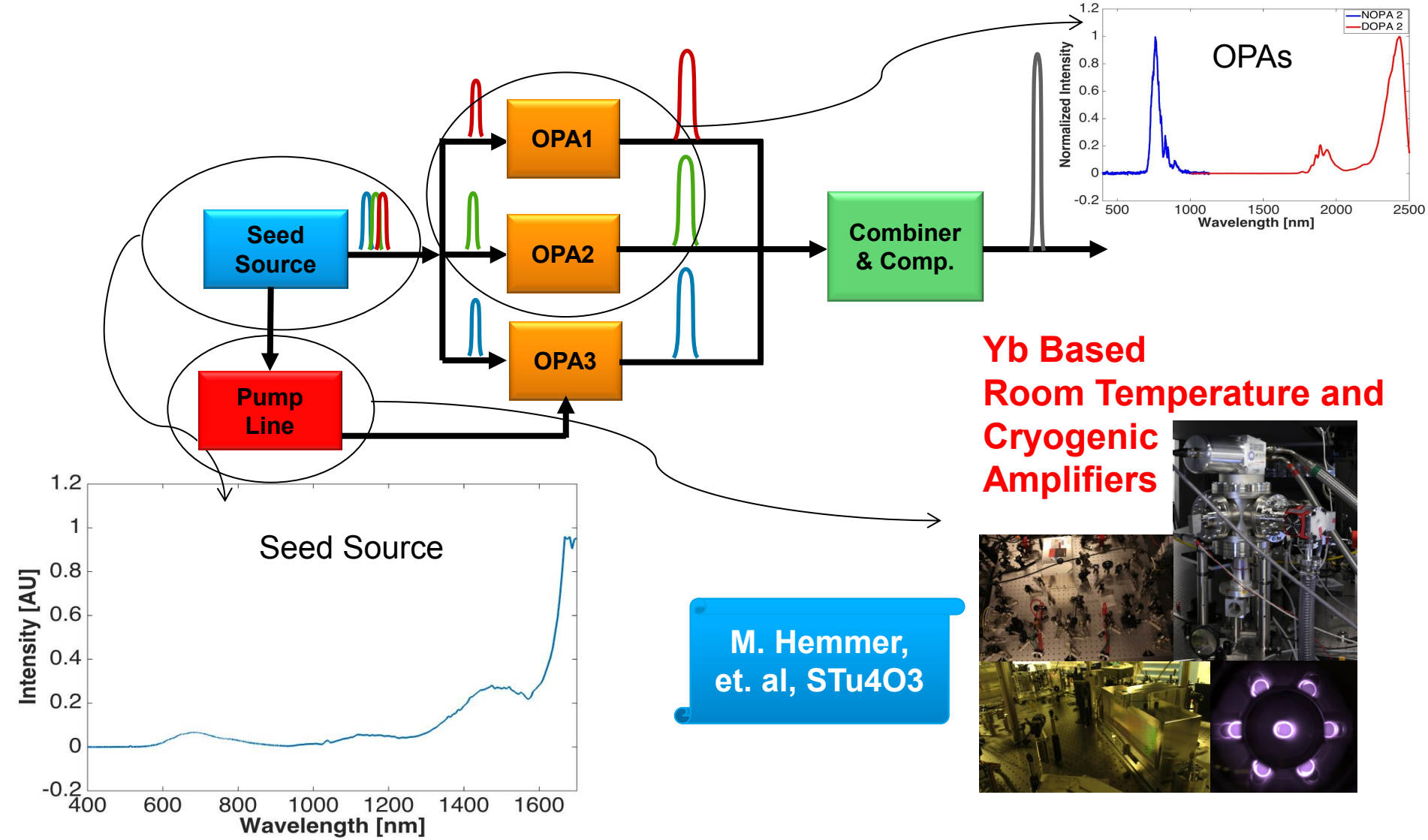
Huang et al., Nature photonics, **5**, 475 (2011)
Hong et al. Optics Letters, **39**, 3145 (2014)

Ti:Sapphire based pump technology



Cirmi et al., UFO IX, **We3.3**, (2013)
Manzoni et al, Laser&Photonics Review (2015)

Our Planned System

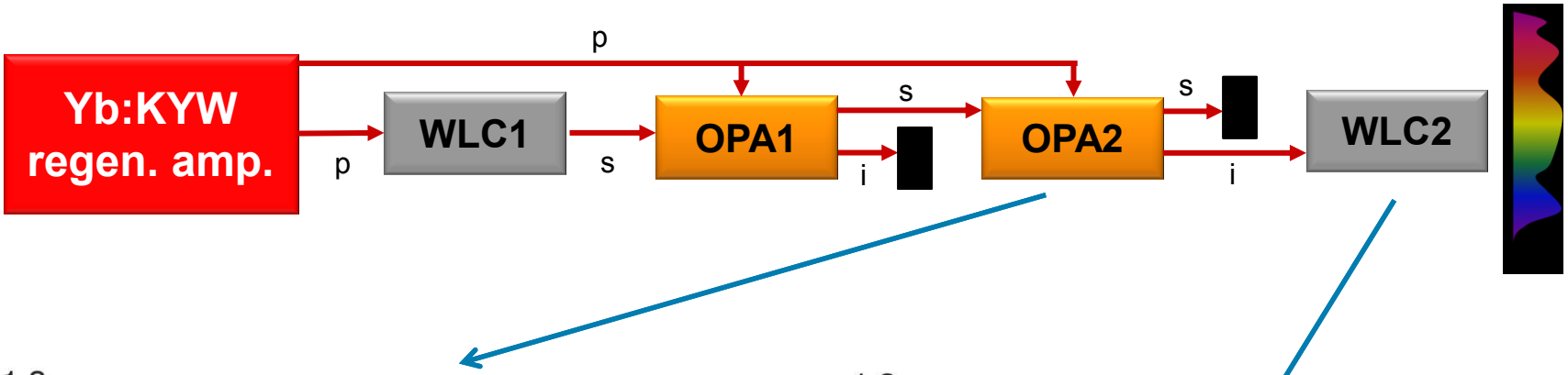


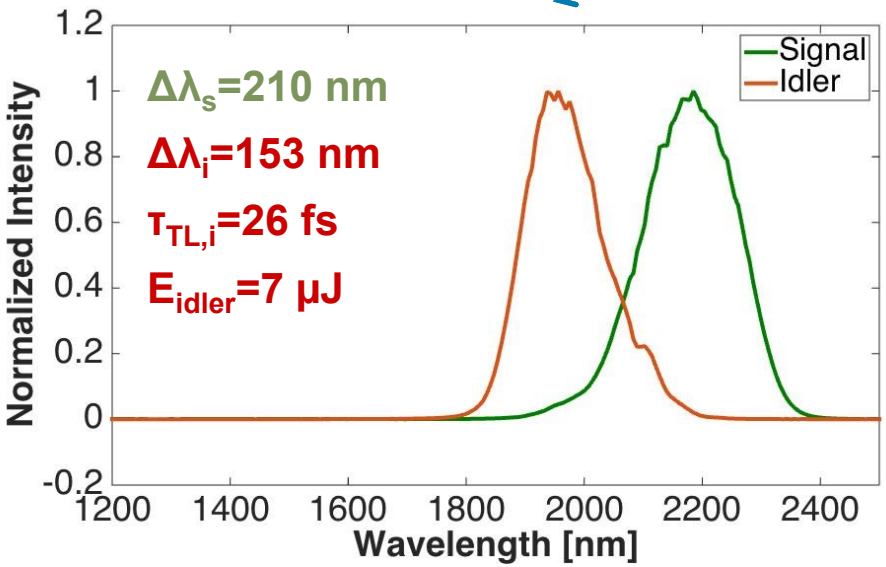
Yb Based Room Temperature and Cryogenic Amplifiers

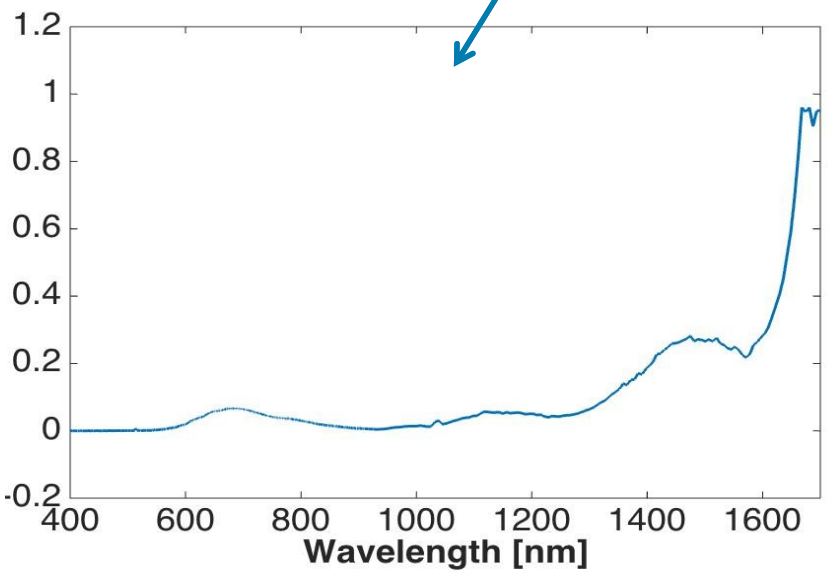
M. Hemmer, et. al, STu4O3

A-L Calendron et.al, Optics Express, **22**, 24752 (2014)
K-H Hong et. al, Optics Letters, **35**, 1752 (2010).
L.E.Zapata et al. Optics Letters (accepted)

Passively CEP Stable Seed Source

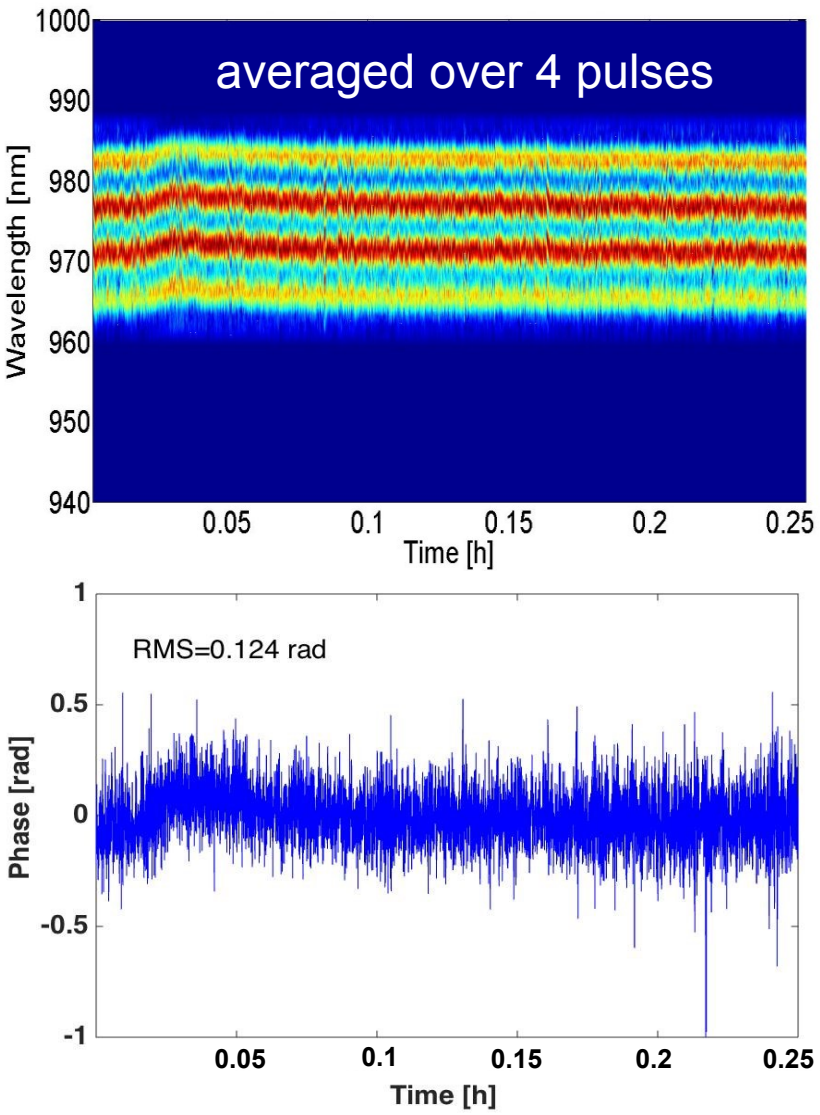


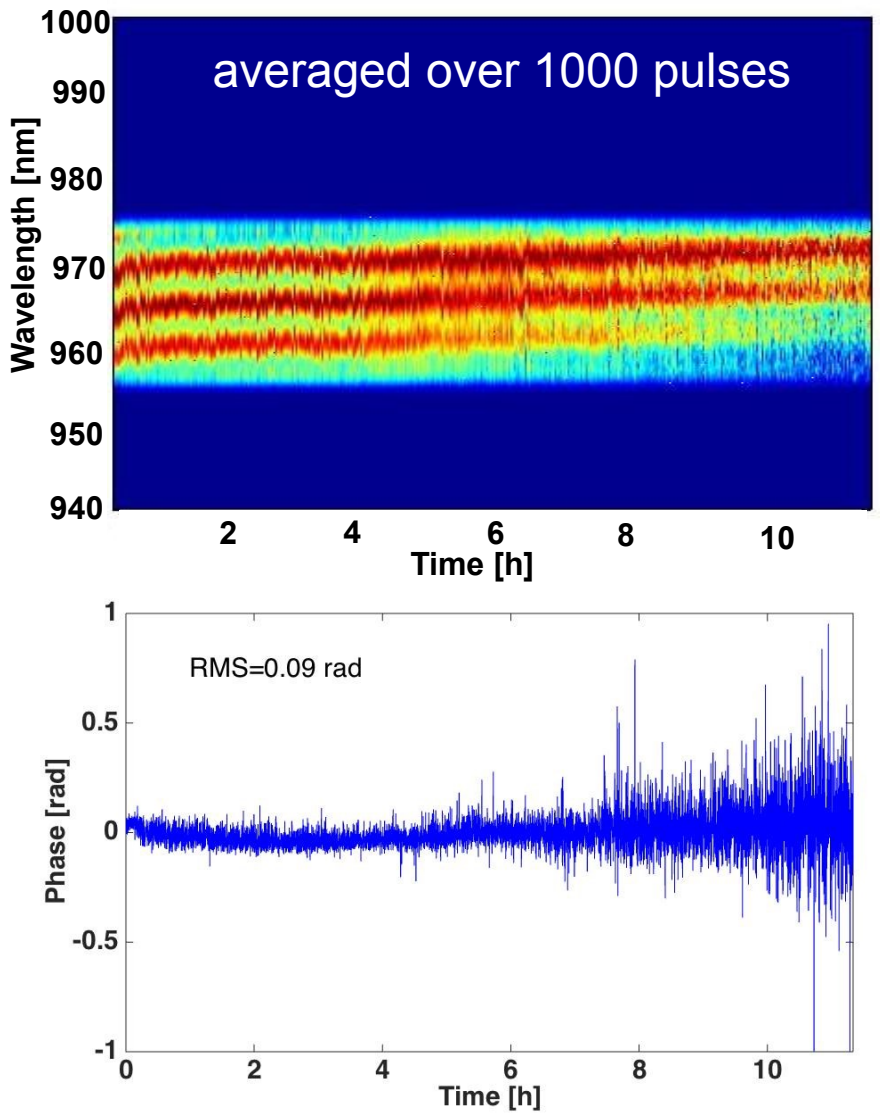




H. Cankaya, A-L Calendron, F.X. Kärtner., Ultrafast Phenomena, Okinawa, (2014)

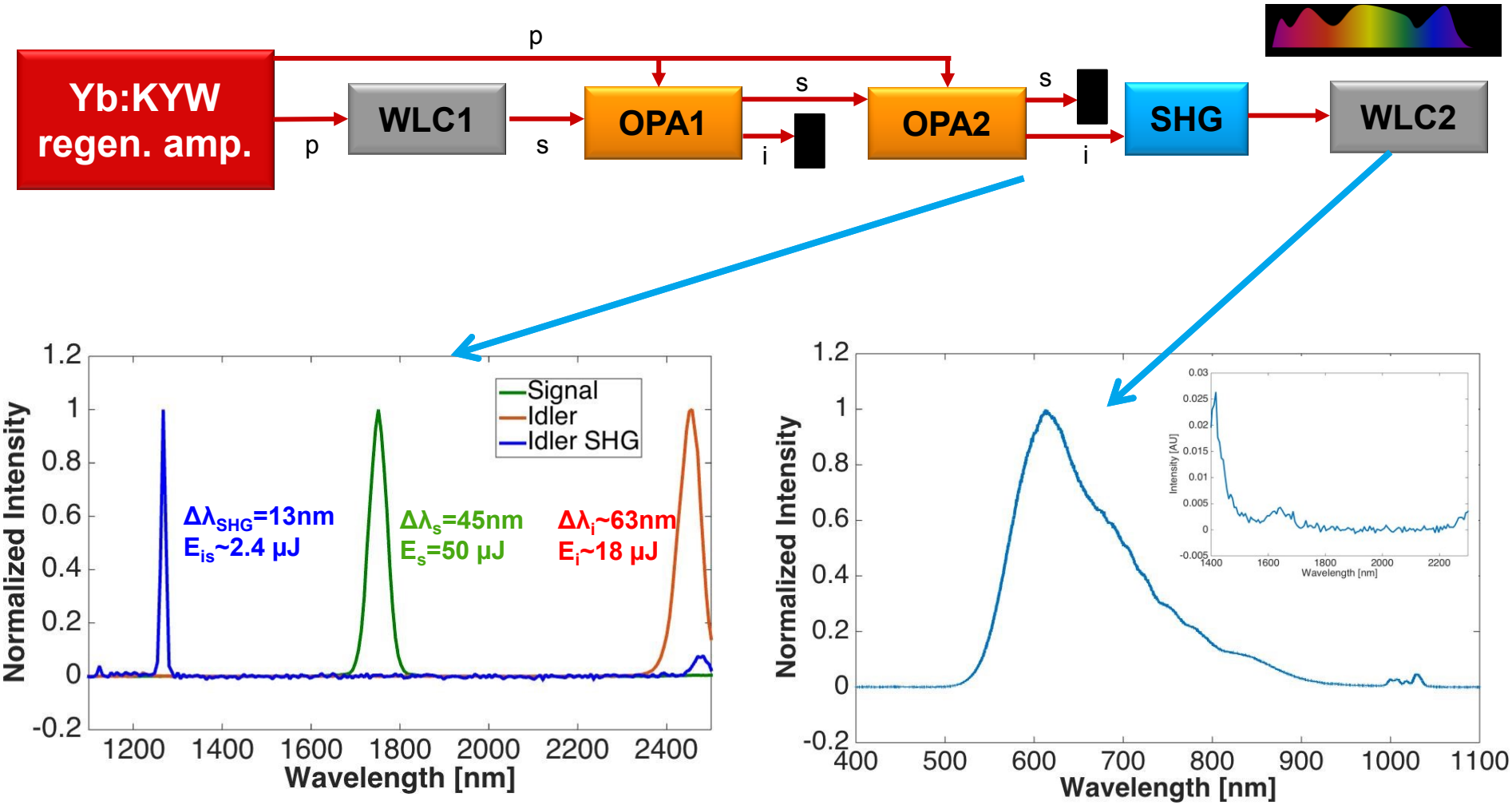
CEP Characterization



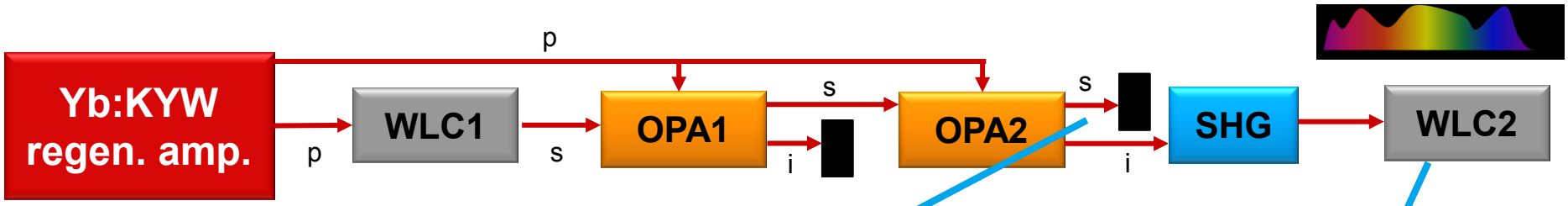


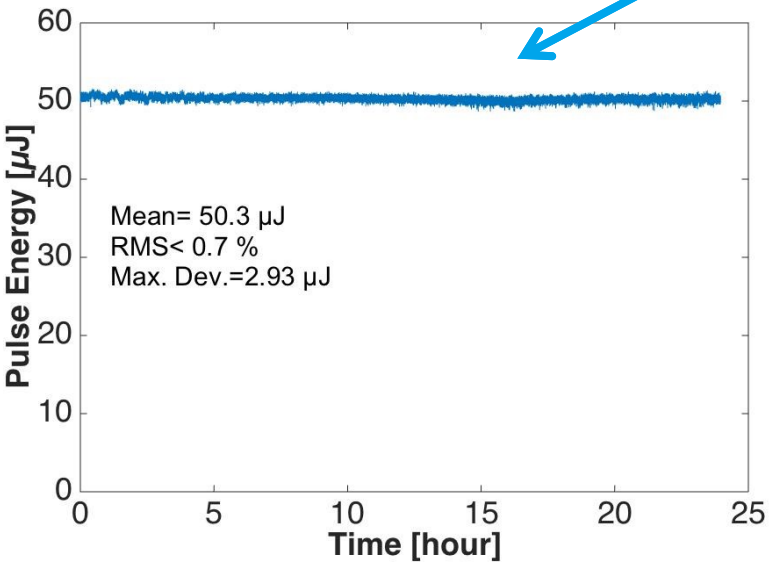
H. Cankaya, A-L Calendron, F.X. Kärtner., Ultrafast Phenomena, Okinawa, (2014)

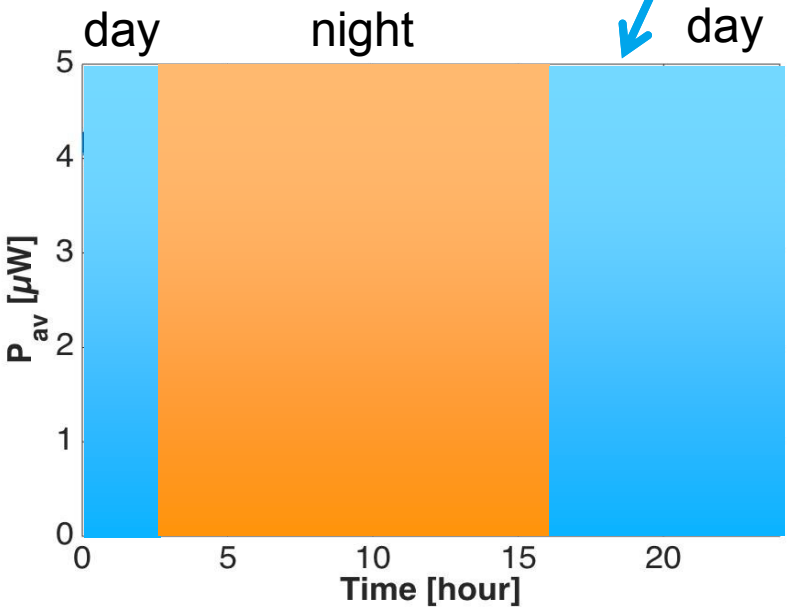
Modification in CEP Stable Seed Source



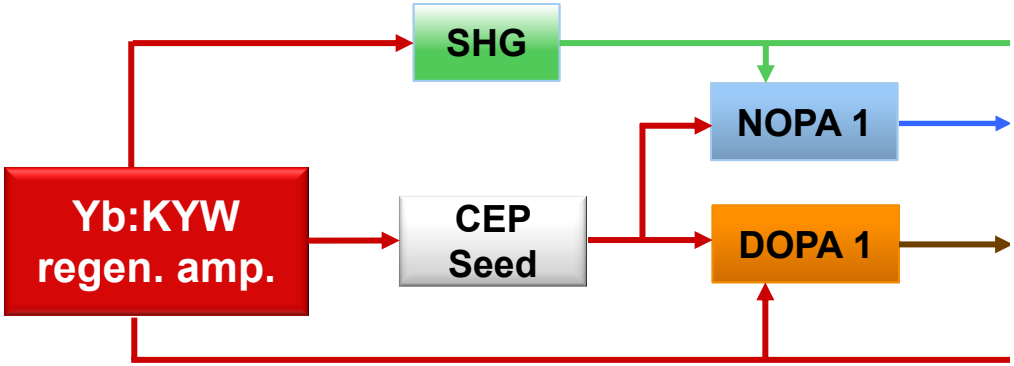
24-Hour Operation of Seed Source

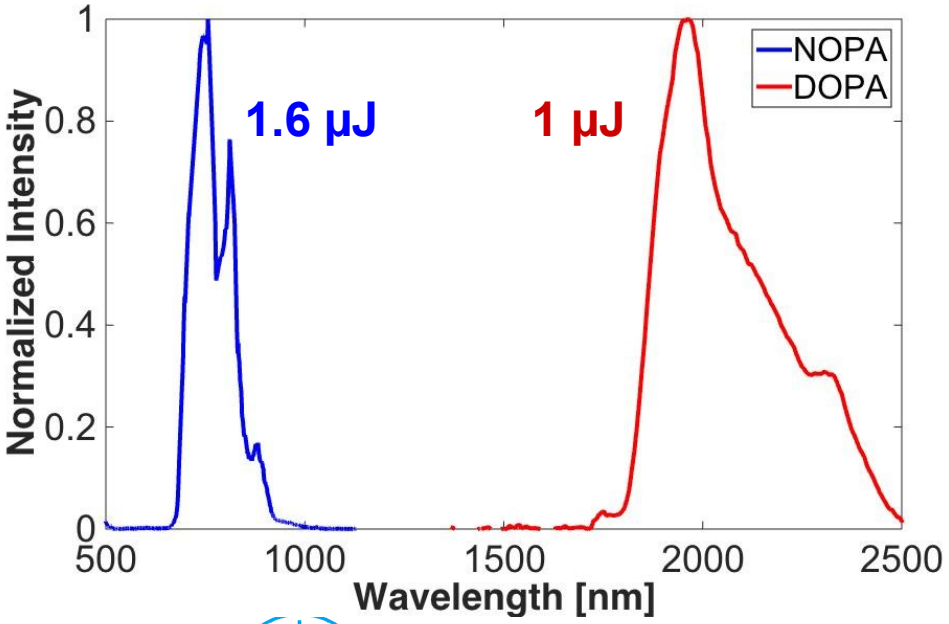






Two Channel OPAs





NOPA Parameters:

- E_p= 24 µJ
- E_s= 1.6 µJ
- I_p= 88 GW /cm^2

DOPA Parameters:

- E_p= 105 µJ
- E_s= 1 µJ
- I_p= 130 GW /cm^2

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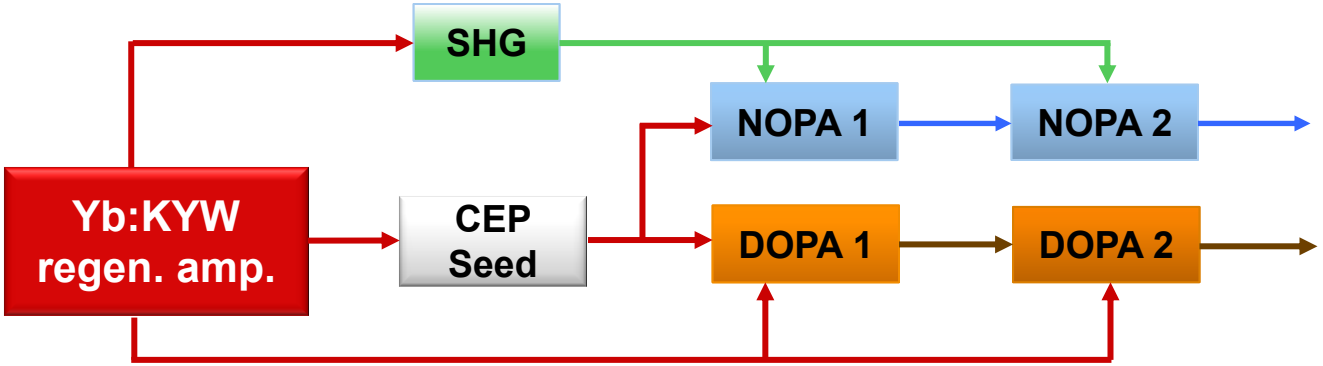
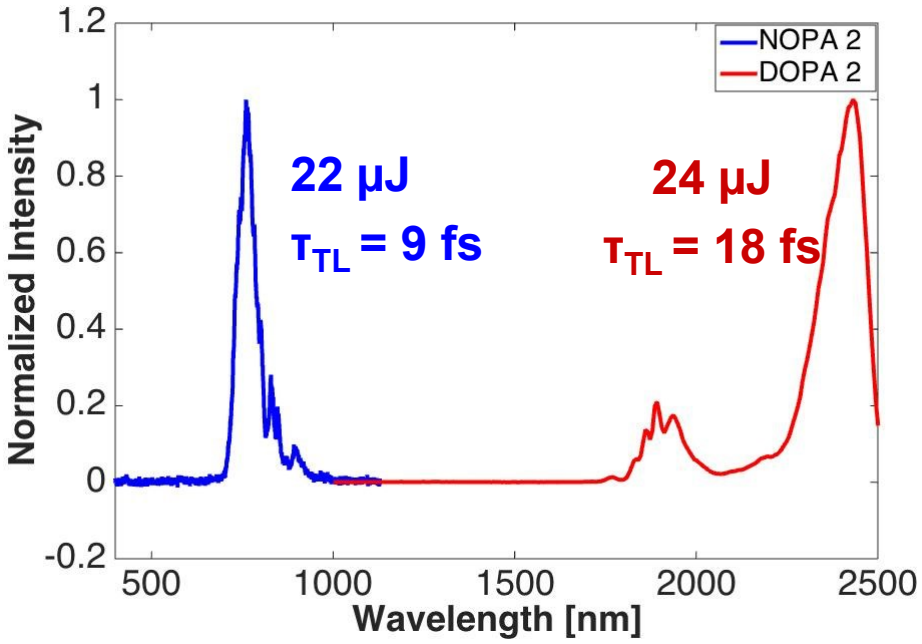
Two Channel OPAs



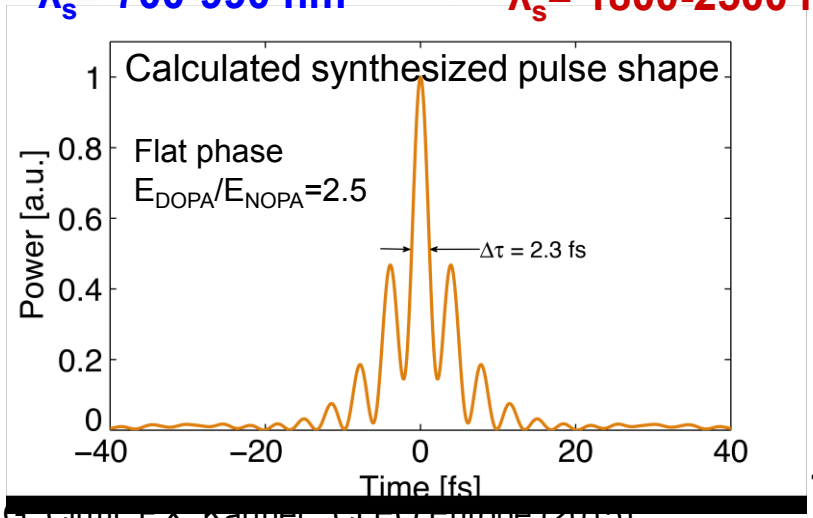


NOPA 2 Parameters:

- E_p= 200 μJ
- E_s= 22 μJ
- I_p= 65 GW /cm^2
- λ_s= 700-990 nm

DOPA 2 Parameters:

- E_p= 470 μJ
- E_s= 24 μJ
- I_p= 69 GW /cm^2
- λ_s= 1800-2500 nm

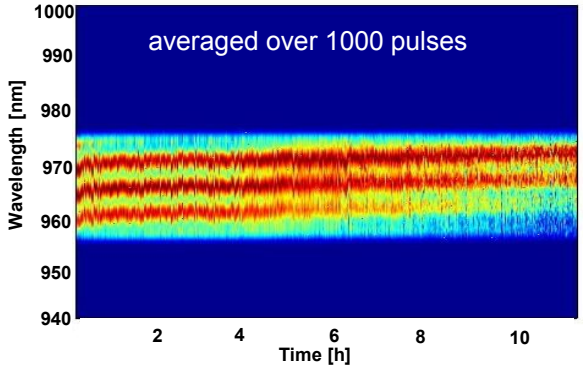


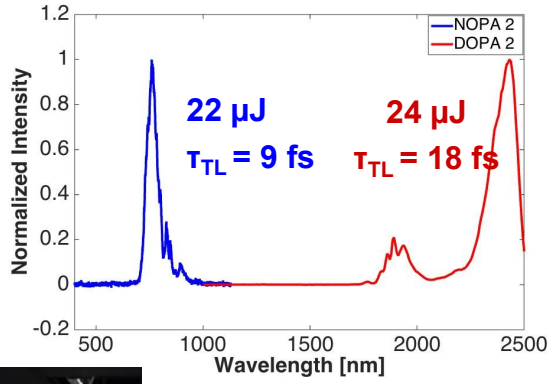
A-L Calendron, H. Cankaya, G. Cirmi, F.X. Kartner., CLEO Europe (2015)

Summary and Outlook

Summary:

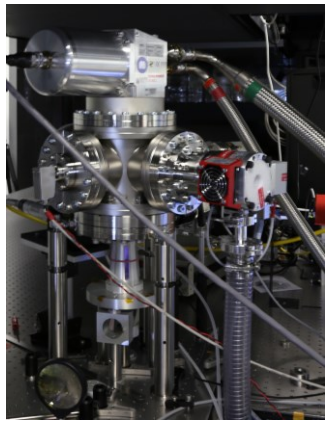
- CEP stable seed source based on Yb pump laser
- CEP stability less than 100 mrad for 11 hour operation
- Two-channel OPA stages 20-μJ pulses per channel

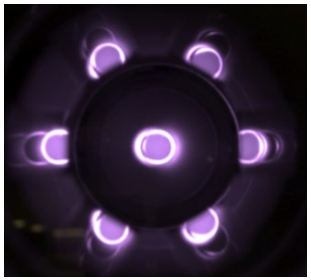




Outlook:

- Amplification to mJ level
- Characterization of spectral-phase and compression
- Pulse synthesis





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Thank you
for your attention