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# University of Pécs in ELI

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# Outline

- ELI tasks
- Research fields & achievements

# Contribution to ELI-tasks

- Nonlinear crystal technology for second-harmonic generation (in A1.1)
- Plasma waveguides (in A8)
- Source of mid–far IR sub-ps pulses (in A9)
  - Design the mid–far IR source
  - Applicability of mid–far IR pulses for low energy charged particle pulse characterization

# ELI PP Workpackages

- Front-end (WP7A-1)
- Laser upgrade (WP7A-7)
- Fundamental researches for the upgrade of the secondary sources (WP7B-6)

# Relevant research fields

- Femtosecond nonlinear optics
- High-energy THz pulses
- X-ray laser & capillary waveguides

# High-power few-cycle pulses from OPCPA

- Short-pulse optical parametric chirped-pulse amplification for the generation of high-power few-cycle pulses

  Fülöp, et *al.*, New J. Phys. 2007

# High-power few-cycle pulses from OPCPA

## Concept

- OPCPA pumped by short (100 fs – 1 ps) pulses (instead of ~100 ps)

## Features

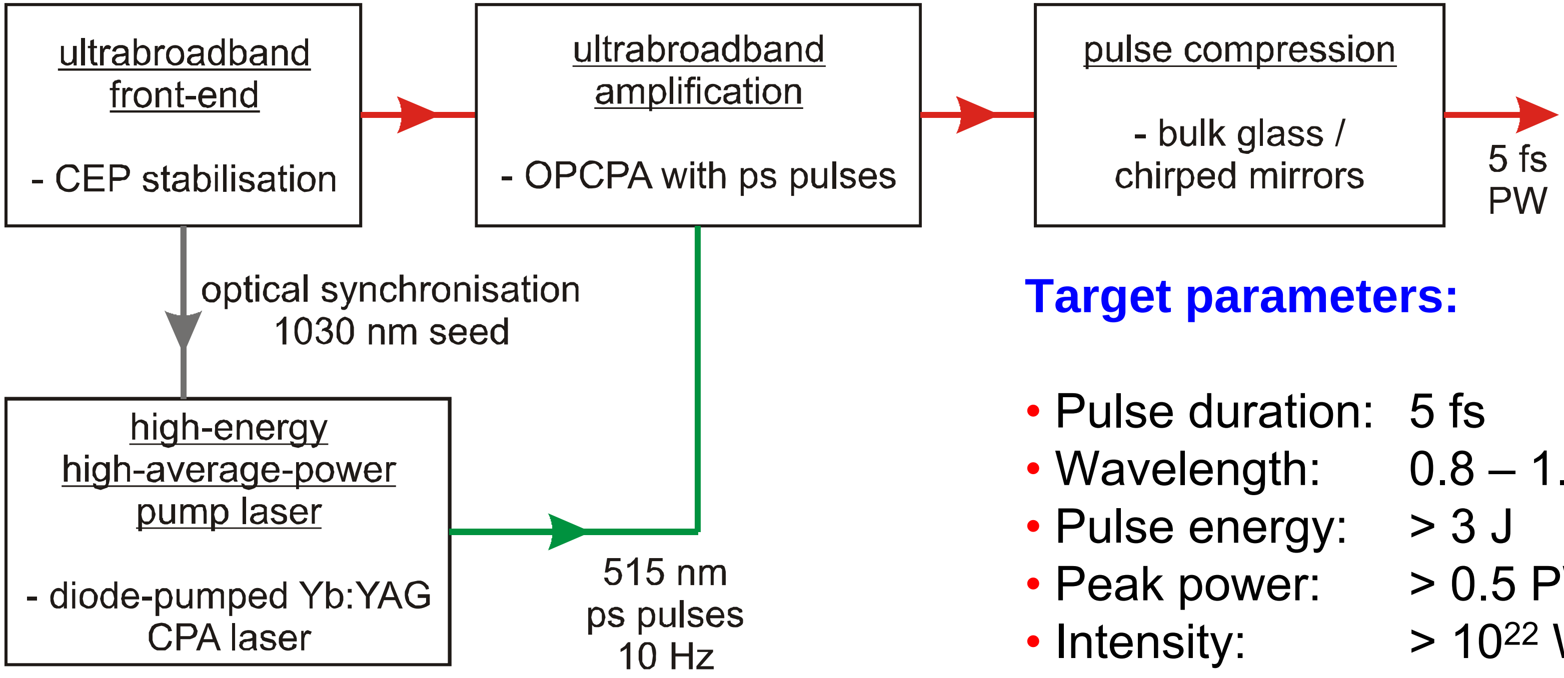
- Short pulse duration
  → small stretching & compression factor for signal
  → chirped-mirror + bulk glass compression
  → much higher pulse contrast

- Increased pump power
  → high gain in thin (~100 μm) OPA crystals
  → increased amplification bandwidth

# The MPQ Petawatt Field Synthesizer (PFS)

- **Goal:** Ultra-intense fs–as pulses of
  - IR to XUV light
  - X-rays
  - particles

  for exciting & probing matter with atomic resolution in time & space
- **Tool:** PFS – waveform-controlled few-cycle laser pulses with PW peak power




**Target parameters:**

- Pulse duration: 5 fs
- Wavelength: 0.8 – 1.6 μm
- Pulse energy: > 3 J
- Peak power: > 0.5 PW
- Intensity: > $10^{22}$ W/cm$^2$
- Repetition rate: 10 Hz
- Carrier-envelope phase control

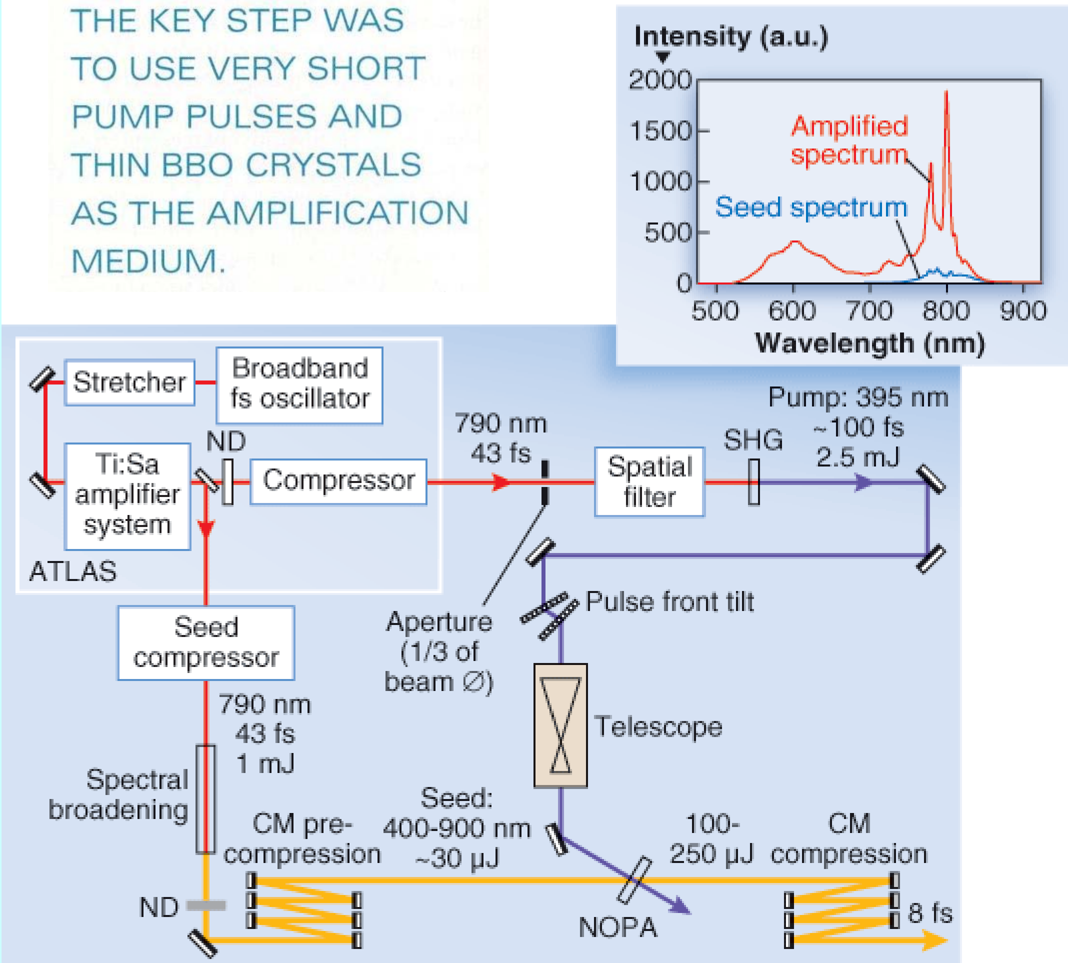
# Short-pulse-pumped OPCPA

optoelectronic worldnews

PULSE AMPLIFICATION

## Few-cycle pulses get seriously powerful

THE KEY STEP WAS TO USE VERY SHORT PUMP PULSES AND THIN BBO CRYSTALS AS THE AMPLIFICATION MEDIUM.



# Generation of THz pulses

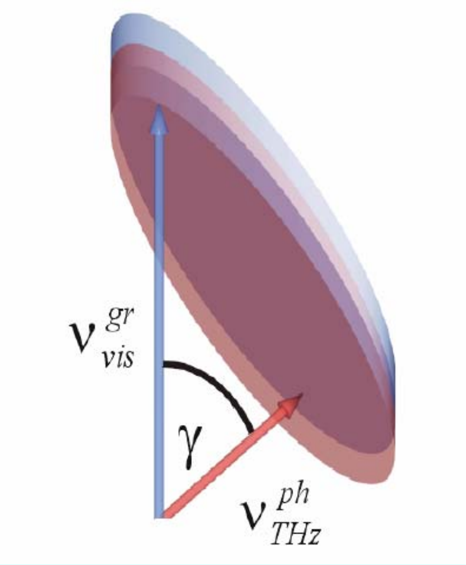
| **Method** | **Field** | **Energy** |
|---|---|---|
| Accelerator-based | 1 MV/cm | 100 μJ |
| Photoconductive switches* | 0,1 MV/cm | 0,5 μJ |
| **Optical rectification*** | **1 MV/cm** | **10 μJ** |
| Laser-induced plasma* | 0,2 MV/cm | 4 μJ |

* using femtosecond laser pulses

# Velocity matching by tilting the pump pulse front

Phase-matching condition:

$$v_{vis}^{gr} \cdot \cos\gamma = v_{THz}^{ph}$$

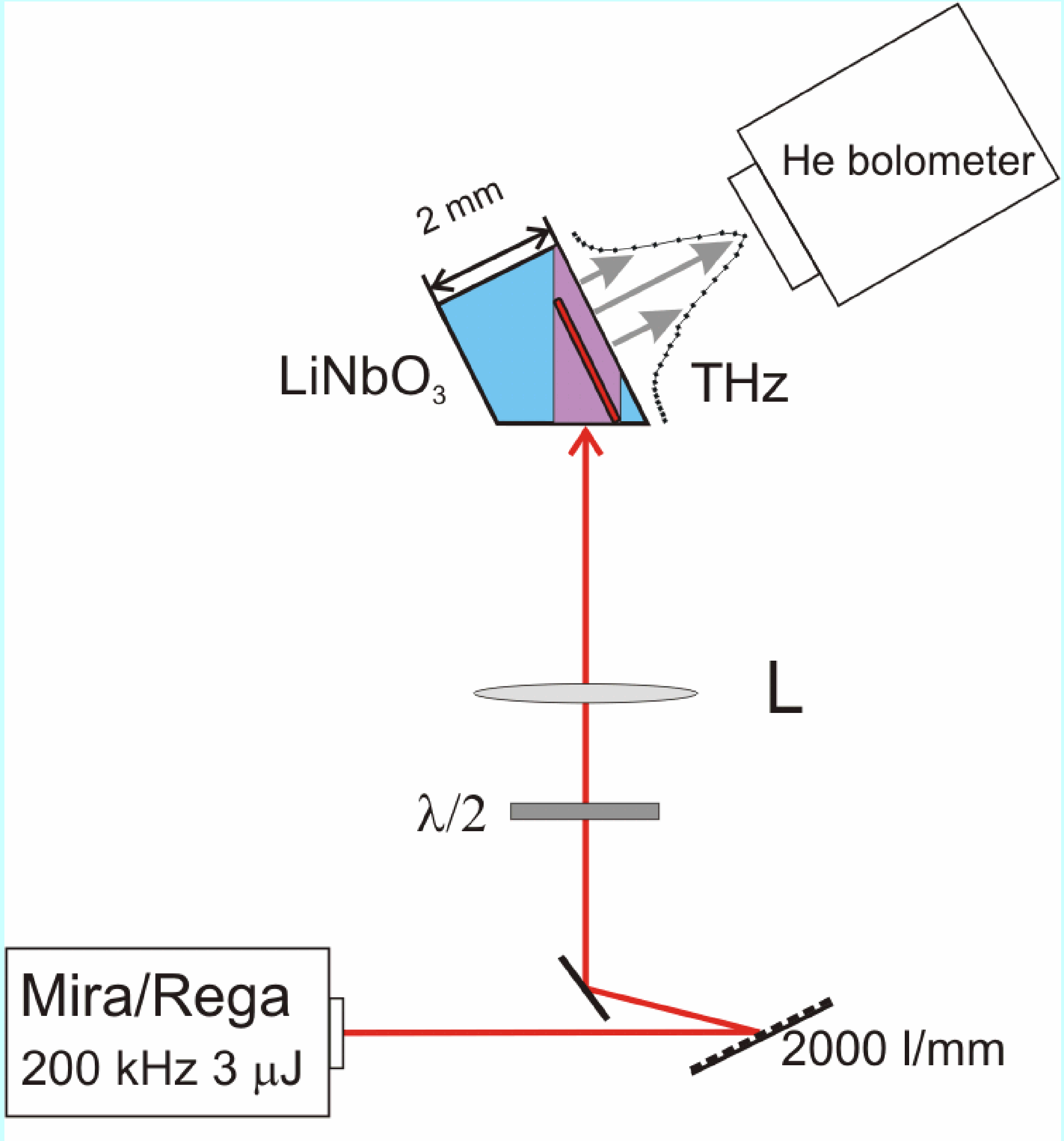



Hebling et *al.*, Opt. Expr. 2002
Stepanov, Hebling, Kuhl, Appl. Phys. Lett. 2003

- No principal limitation on the pump spot size
- THz energy can be scaled up by increasing the pump spot size

Stepanov et *al.*, Opt. Expr. 2005
Yeh, Hoffmann, Hebling, Nelson, Appl. Phys. Lett. 2007
Pálfalvi, Fülöp, Almási, Hebling, Appl. Phys. Lett. 2008

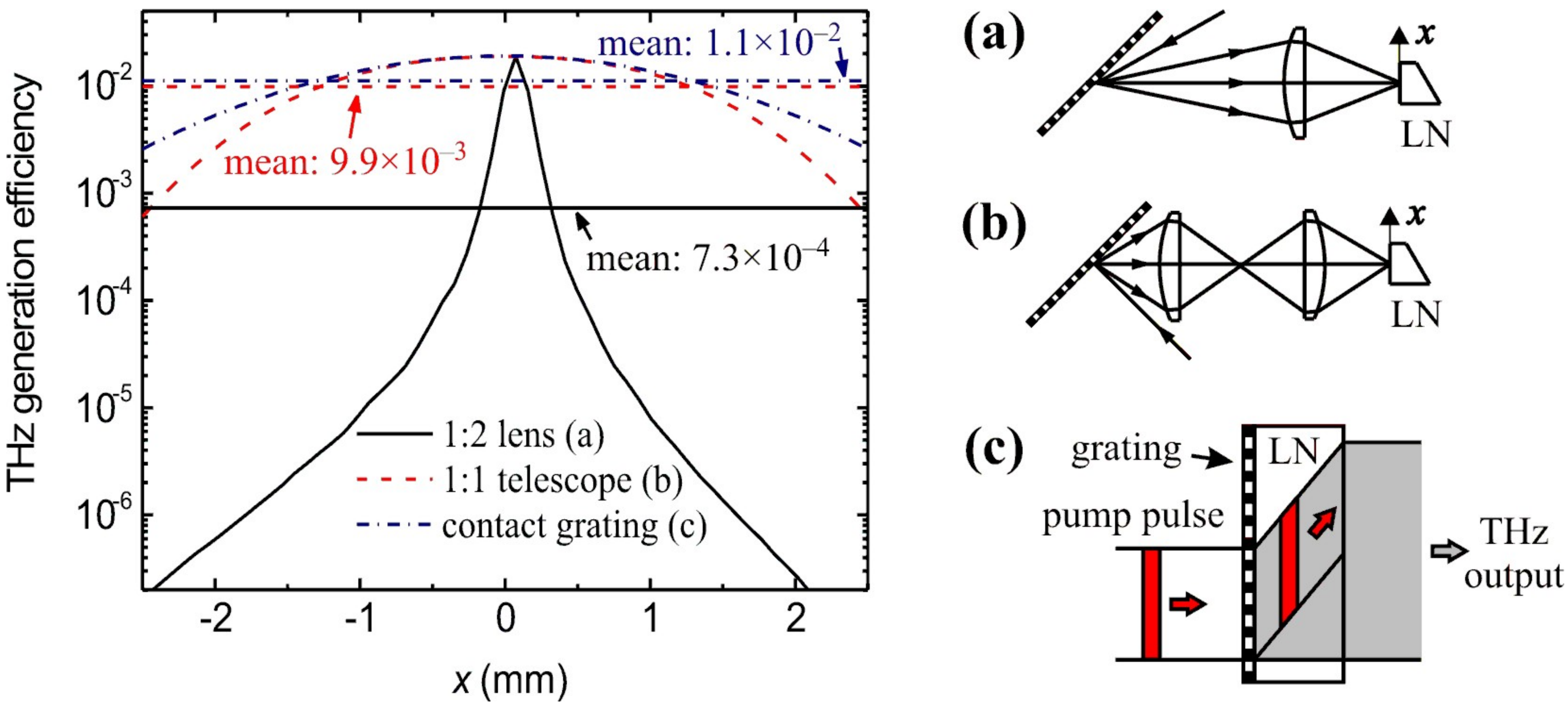
# Velocity matching by tilting the pump pulse front



# Tilted-pulse-front excitation vs. collinear phase matching

| | | |
|---|---|---|
| $E_{THz}$ | **10 μJ** | **1.5 μJ** |
| $E_{pump}$ | **16 mJ** | **48 mJ** |
| Conversion efficiency $\eta$ [$10^{-5}$] | **60** | **3.1** |
| Method | Tilted-pulse-front excitation in $LiNbO_3$ | Collinear phase matching in ZnTe |
| Reference | Yeh et *al.*, 2007 (MIT & Pécs) | Blanchard et *al.*, 2007 |

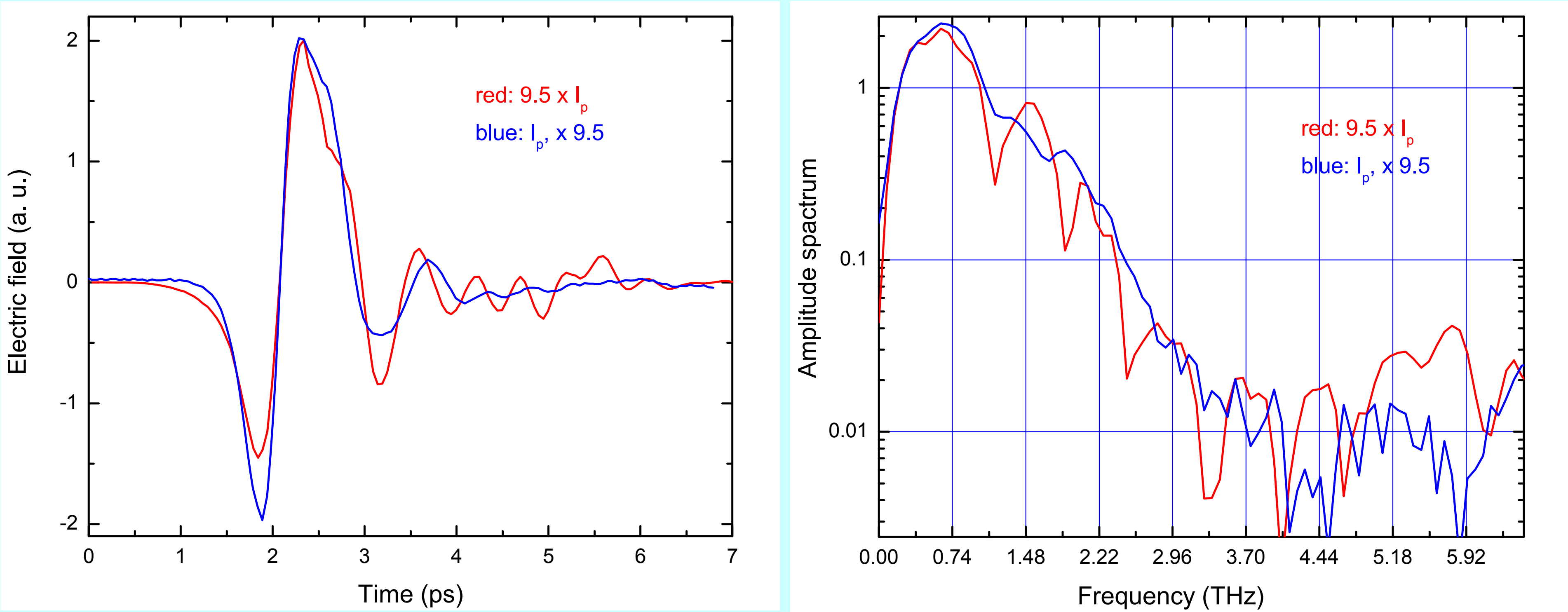
# Extremely high power single-cycle THz pulses




By reducing pulse distortion effects in novel pulse-front-tilting setups → Increase further THz energy by more than one order of magnitude.

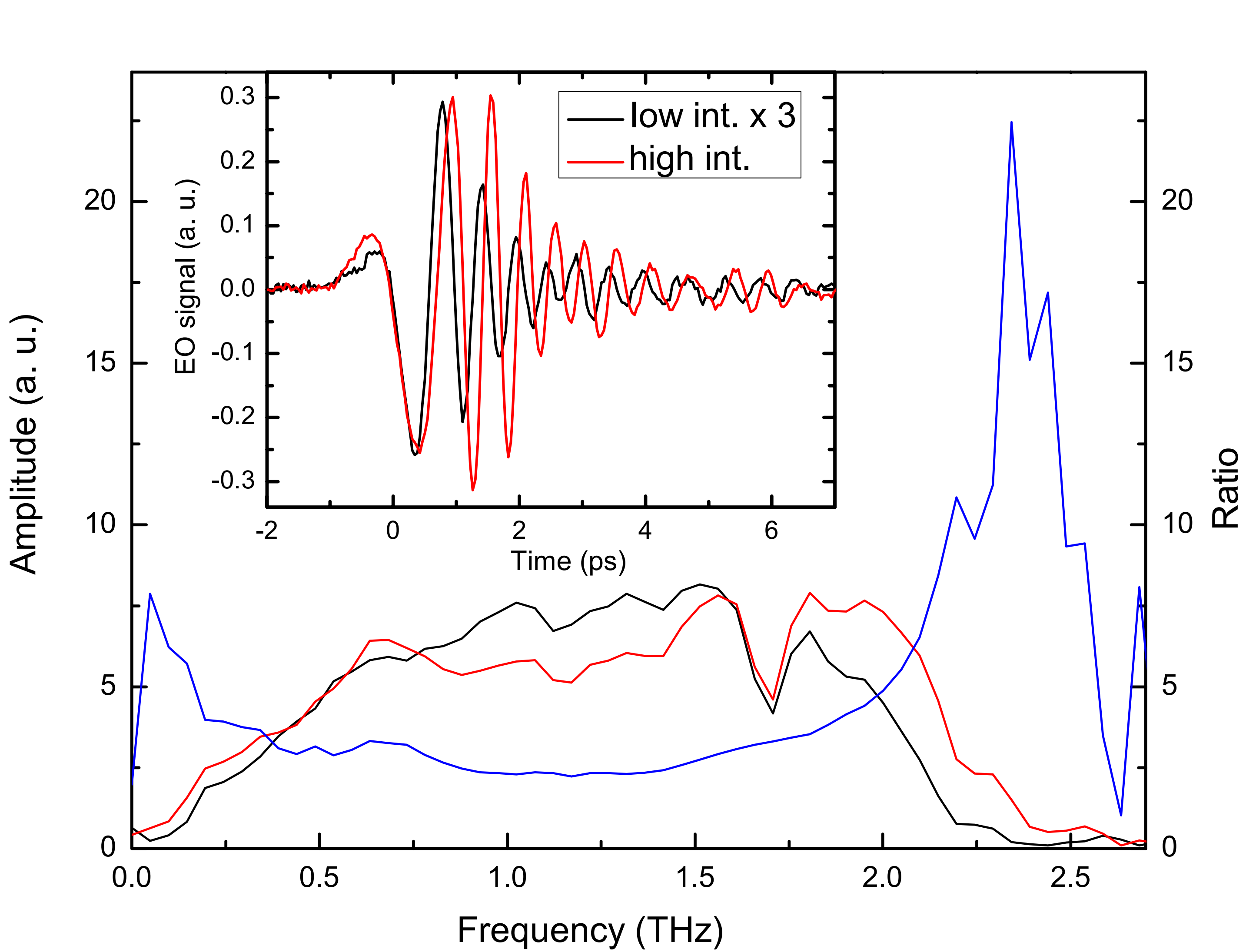
Pálfalvi, Fülöp, Almási, Hebling, Appl. Phys. Lett. 2008

# THz nonlinear optics — Harmonics generation in $LiNbO_3$




Hebling et *al.*, IEEE J. Sel. Top. Quantum Electron. 2008

# THz nonlinear optics — Self-phase modulation in $LiNbO_3$




Ratio of high- to low-intensity spectra

Hebling et *al.*, IEEE J. Sel. Top. Quantum Electron. 2008

# THz nonlinear optics & spectroscopy

High-Power THz Generation, THz Nonlinear Optics and THz Nonlinear Spectroscopy

Hebling, Yeh, Hoffmann, Nelson, CLEO 2008, invited talk

- Nonlinear lattice response observed through THz SPM in $LiNbO_3$
- Nonlinear optical responses in Ge in the THz range

# Ultrafast THz Laboratory at University of Pécs

## Basic infrastructure

- High-energy femtosecond light source for driving THz-pulse generation
- Tilted-pulse-front THz generation setup
- Pyroelectric power meter
- Electro-optic THz sampling set-up

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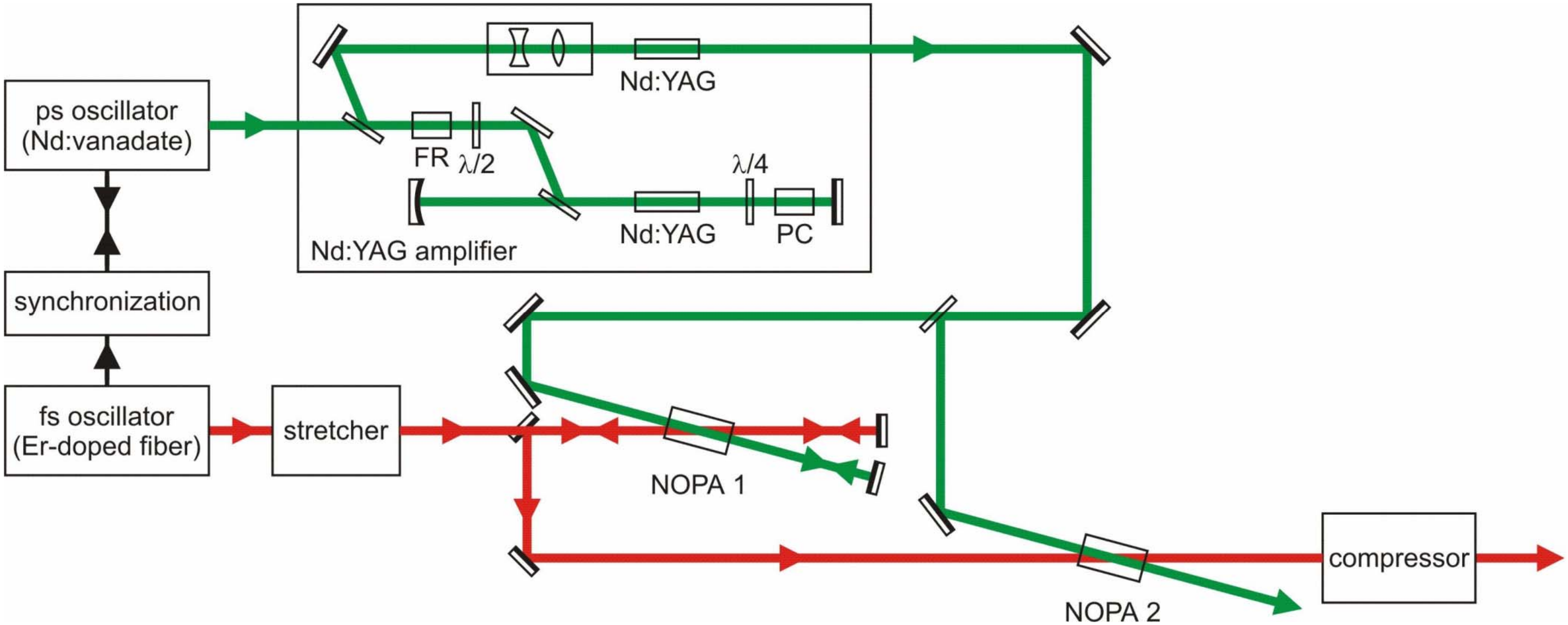
Ultrafast THz Lab

# The high-energy femtosecond light source

Target parameters:

- wavelength 1.5 μm
- pulse duration 100 fs
- pulse energy 1 mJ (10 mJ)
- repetition rate 20 Hz



# THz & Nonlinear Optics Group at University of Pécs

Almási Gábor

Bartal Balázs

Fülöp József

Hebling János

N. N.

Pálfalvi László

Tóth György

# Cooperations

- MIT, Deptartment of Chemistry Boston, USA

  **M. C. Hoffmann, K.-L. Yeh, K. A. Nelson**

- Max-Planck-Institute for Quantum Optics Garching, Germany

  **F. Krausz group**

- Institute for Solid State Physics Budapest, Hungary

  **K. Polgár, Á. Péter**

- University of Munich Germany

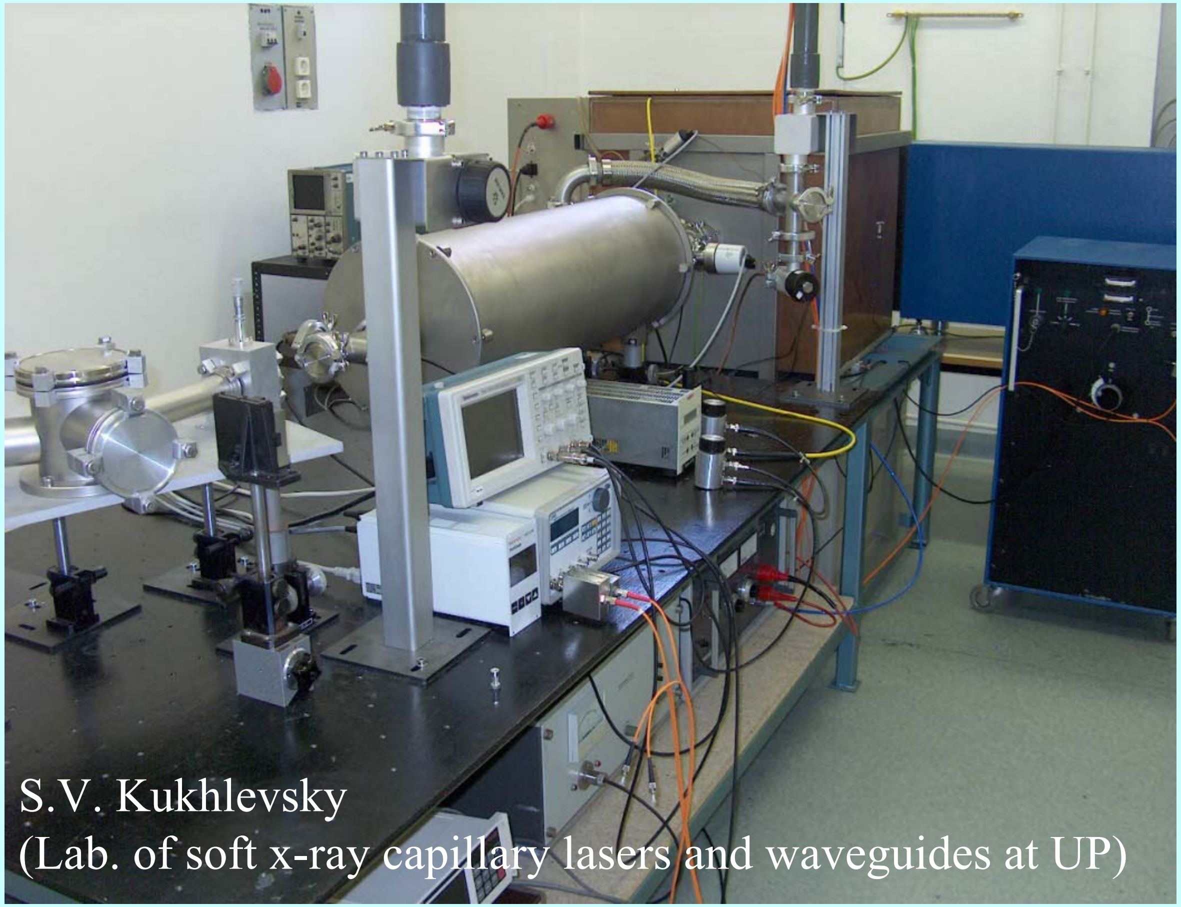
  **E. Riedle**

- Max-Planck-Institute for Solid State Research Stuttgart, Germany

  **A. G. Stepanov, J. Kuhl**

# $Ar^{+8}$ laser by capillary z-pinch at UP

$\lambda$ = 46.9 nm, E ~ 0.3 mJ, $\tau$ = 1.5 ns, $\varphi$ = 0.5-5 mrad, PRR ~ 1 Hz




Kukhlevsky, S.V., et al., SPIG 2006;
Kukhlevsky, S.V., et al., ICNSP&APPTC2005

Diagnostics:
JOBIN YVON TGS 300 (10-110 nm)
XRD, MCP-CCD
Cooperation:
KFKI and Univ. of Szeged, Hungary

Italian-Hungarian joint project 1997-2004:

Kukhlevsky, S.V., et al., SPIE Vol. **3156**, 180 (1997); Kukhlevsky, S.V.,et al., *J. de Physique IV France*, **11**, 583 (2001); Kukhlevsky, S.V., et al., *Plasma Source Science Tech.* **10**, 567 (2001); Tomassetti, G., et al., *Czech J. Phys.* **52** 405-416 (2002); Tomassetti, G., et al. *The Eur. Phys. J.* D, **19**, 73 (2002); Tomassetti, G., et al, *Europhys. Lett.*, **63**, 681 (2003); Ritucci, A., et al., *Europhys. Lett.*, **63**, 694 (2003); Tomassetti, G., et al., *Opt. Comm.* **231**, 403 (2004); Ritucci, A., et al. *Appl. Phys. B*, **78**, 965 (2004)

# Summary

1. ELI-relevant research fields:
   - Femtosecond nonlinearoptics
   - Sub-ps THz optoelecronics
   - X-ray laser & capillary waveguides
2. Singel-cycle THz pulses with 10 $\mu$J energy were demonstrated from optical rectification in $LiNbO_3$ using tilted-pulse-front-excitation.
3. Further substantial increase of the THz energy is within reach.
4. New field of research: Subpicosecond THz nonlinear optics & spectroscopy.
5. Ultrafast THz Laboratory is being established at University of Pécs.