Laser developments for pump-probe experiments at SwissFEL

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SwissFEL laser group

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THz gap: 0.1- 15 THz (3 mm-20 µm)

IR: 15-300 THz (20 - 1 µm)

useful for FEL facilities

- *photon diagnostics for FELs*
- *experiments*

Pulse characteristics

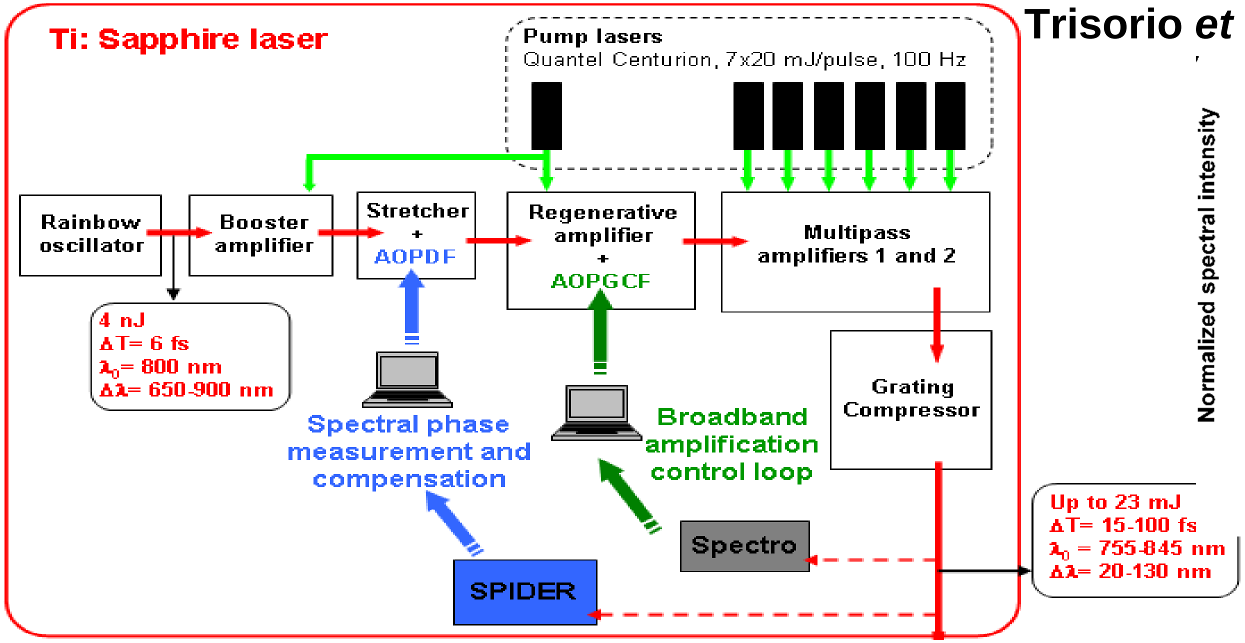
- *many cycles/single-cycle*
- *broadband spectrum*
- *high fields*
- *carrier envelope phase stabilized/controlled*

- *close to experiments*
- *synchronized to FEL, and other laser sources*

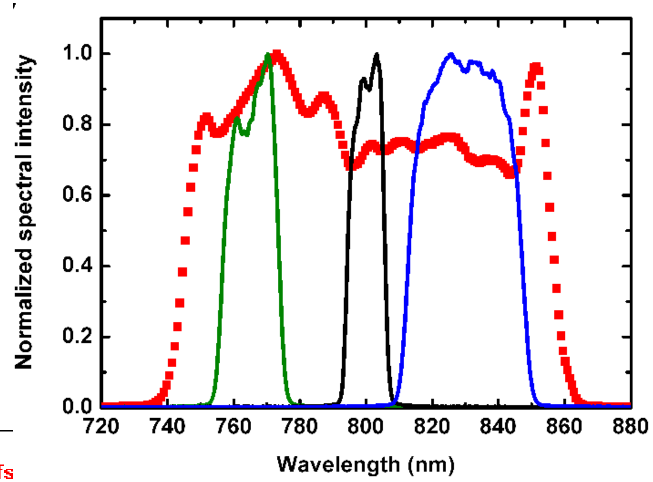
Content

- **Frontend laser system**
- **Terahertz laser** — Organic crystal as optical rectifier; broadband, single cycle pulses; carrier-envelope phase
- **Infrared few cycle pulses** — NL pulse compression by filamentation
- **Implementation at SwissFEL endstation**
- **HHG beamline at PSI** — Seeding towards shorter wavelengths
- **Conclusion**

Front end laser system



Trisorio *et al* Opt. Express 19, 20128, (2011)



- *λ tuning*
- *variable Δλ*
- *multi color amplification*
- *intense pulses from 15 (TL) – 100 fs (TL)*

Front end laser system

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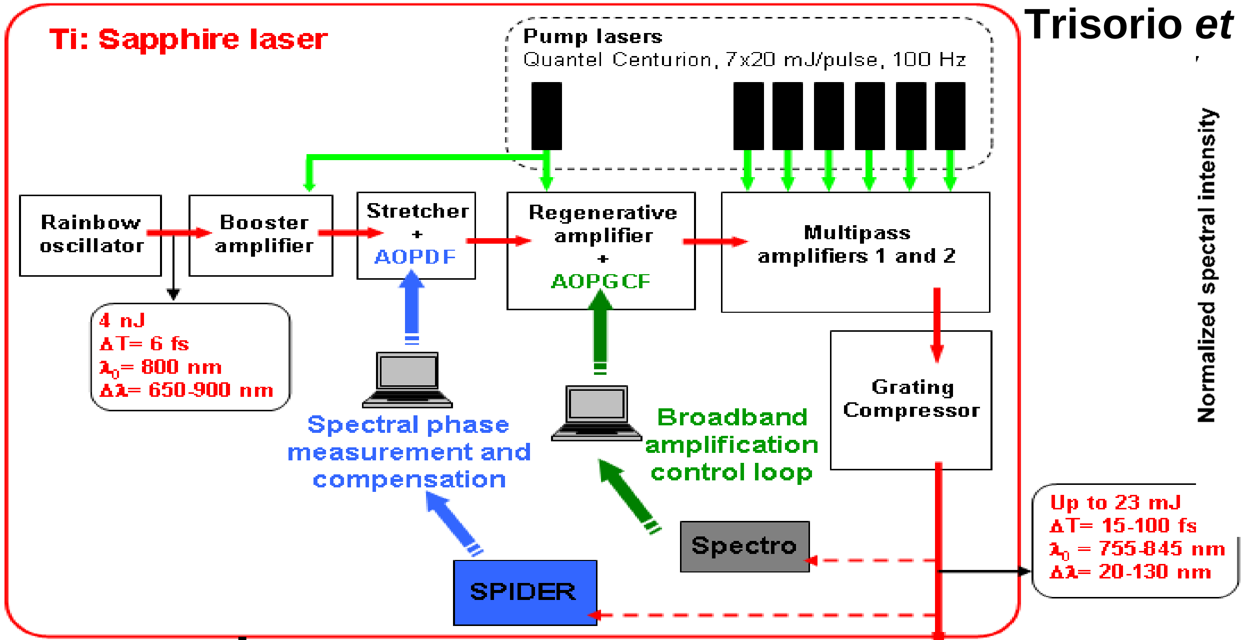
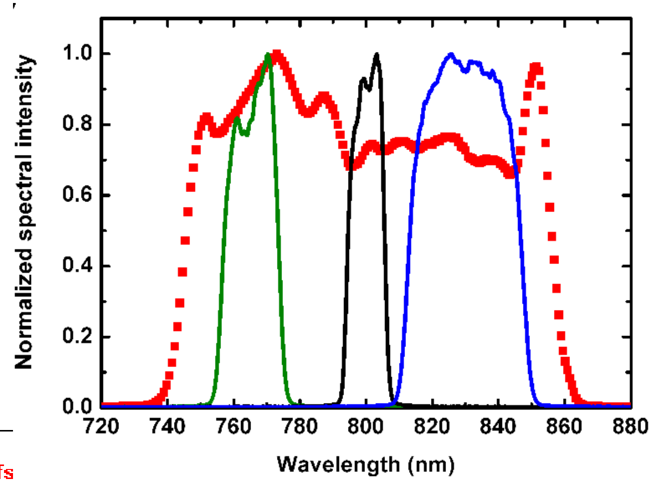


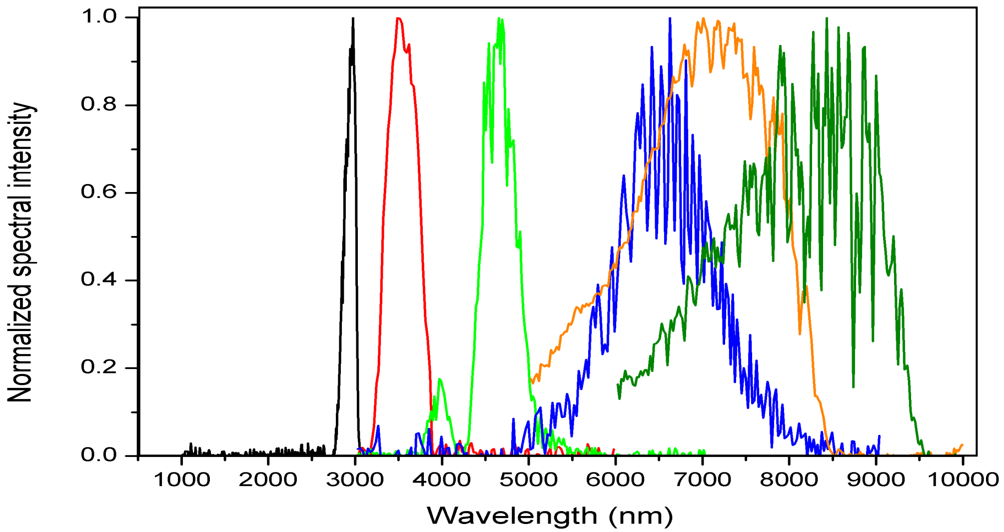


OPA 1

1.3-2.6 µm
70 fs
≈7 mJ

	λ [µm]	ν[THz]	τ[cycles]	process
THz	20 -1000	15 – 0.3	Single	OR
OPA 2	3-20	100-15	few	NDFG
Pulse compression	≈2	150	≈2	DFG+ filament
	1.2 – 2.6	250 - 125	many	DFG
OPA 3	0.2-0.9	1500-300		SFG+SHG

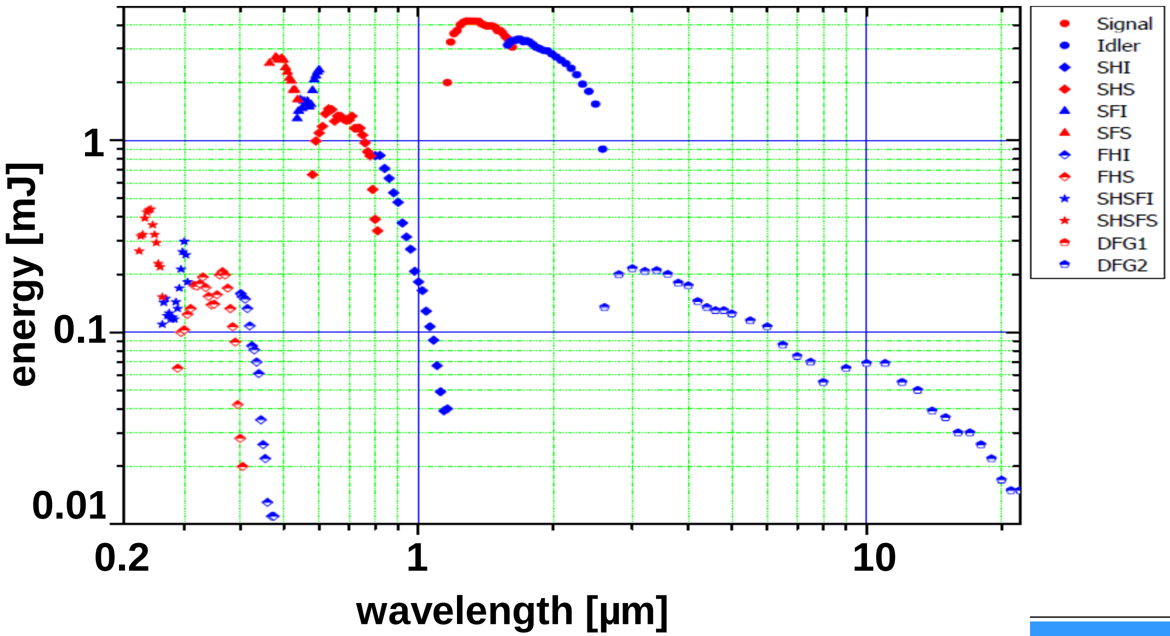
OPA UV-VIS-IR

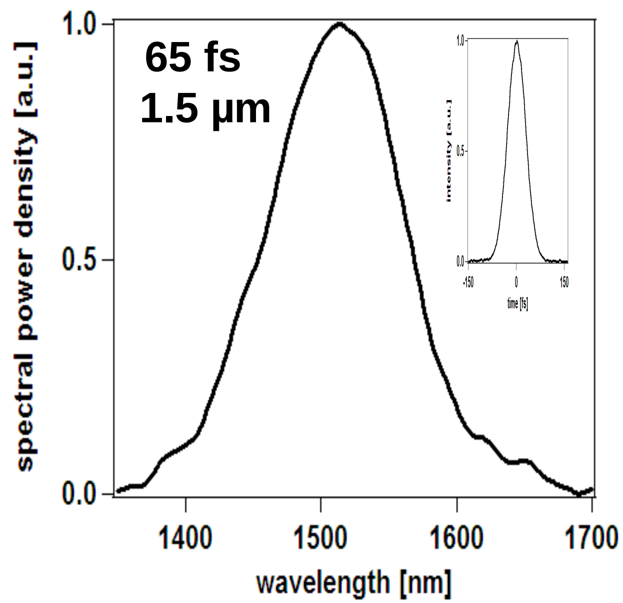


- 25 mJ input at 50fs
- focused intensities exceeding 10^{14} W/cm^2 up to 2600nm
- Sub-mJ in the UV and up to 20µm

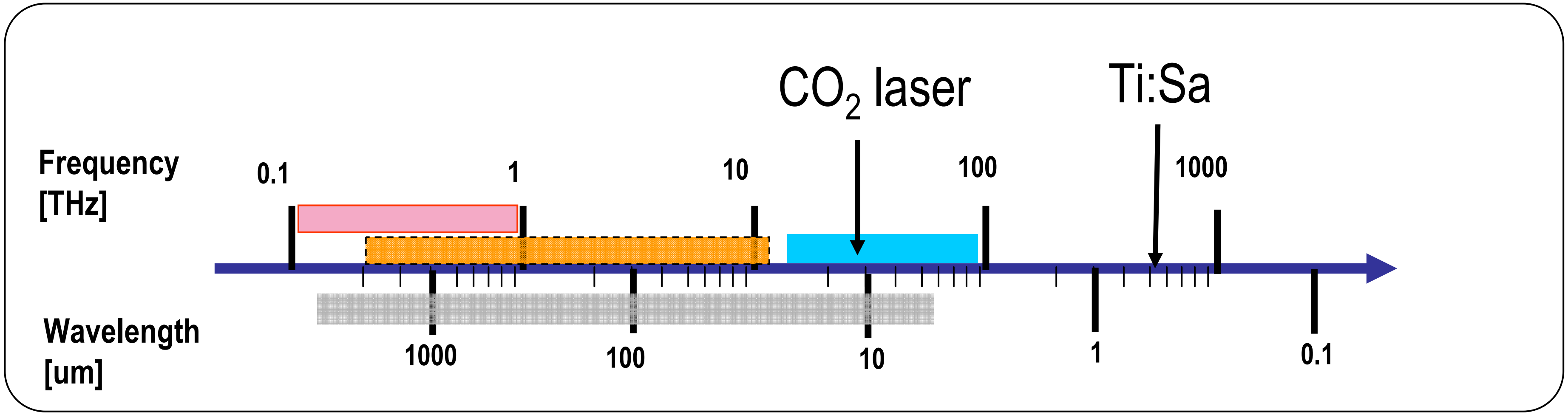
Applications:

- ≈1.5 µm to pump THz
- few cycle probe generation
- tuneable UV source for cathode studies
- absorption spectroscopy

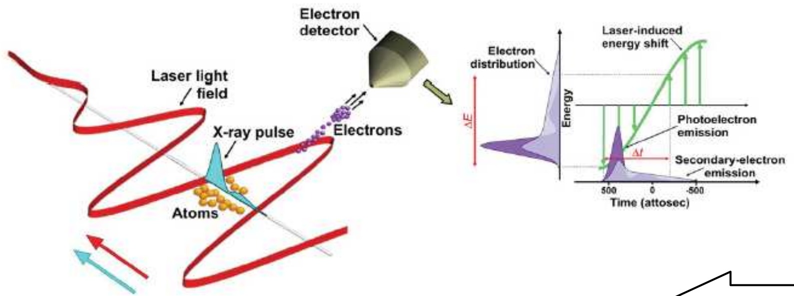




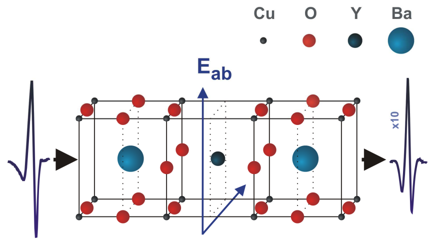
Laser-based THz generation - overview

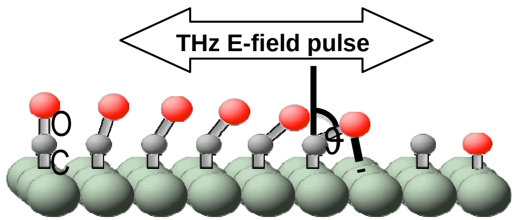


Many dynamical processes occur in the THz region (meV)

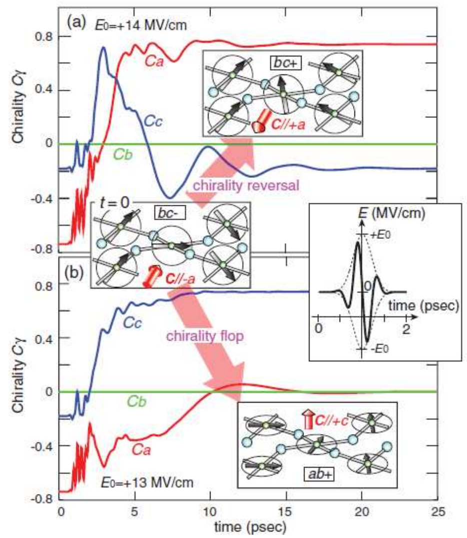


Nature Photonics 3, 523 (2009)





CHIMIA 65, No. 5, 323 (2011)



PRL 105,147202 (2010)

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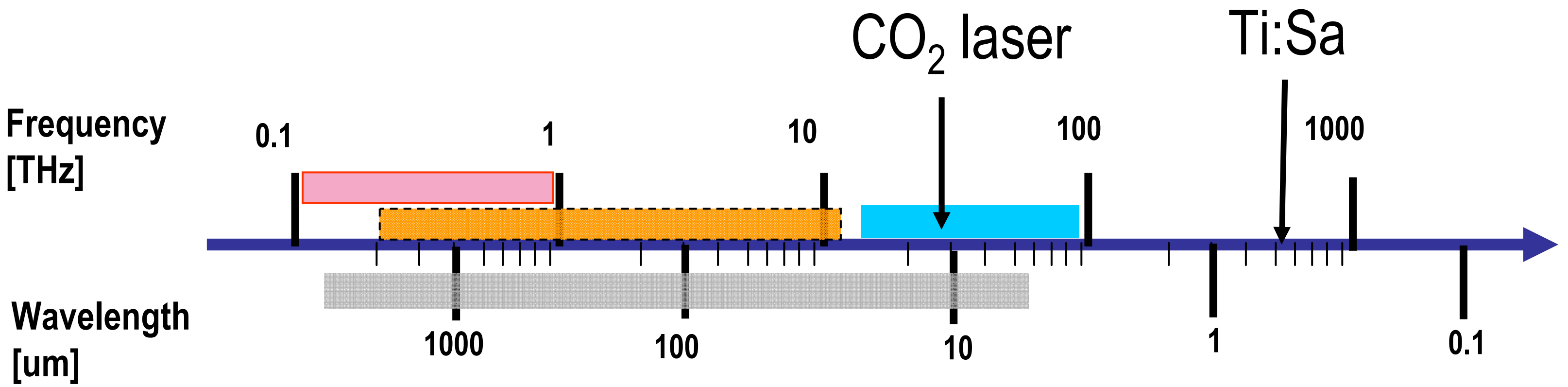


Rectification in $LiNbO_3$

Opt. Lett. 33, 2497 (2008)
Opt. Lett. 37, 557 (2012)

Rectification organic crystal

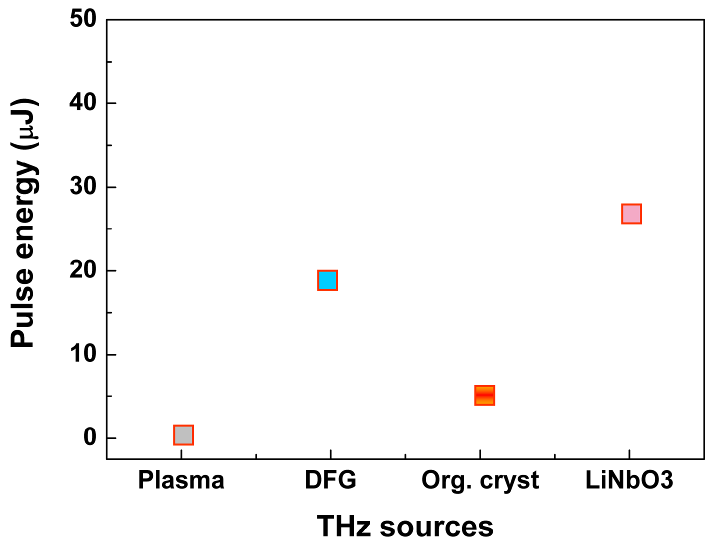
Opt. Expr. 16, 21, 16496 (2008)

Plasma based source

Opt. Lett. 2005, 30, 2805.

Difference frequency generation

Opt. Lett 33,2767 (2008)



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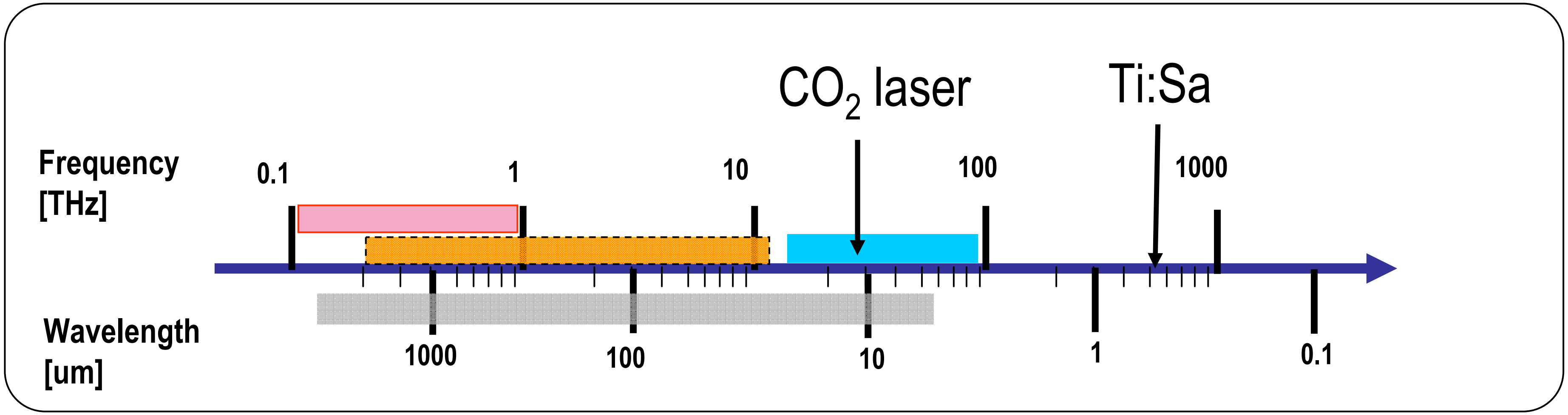

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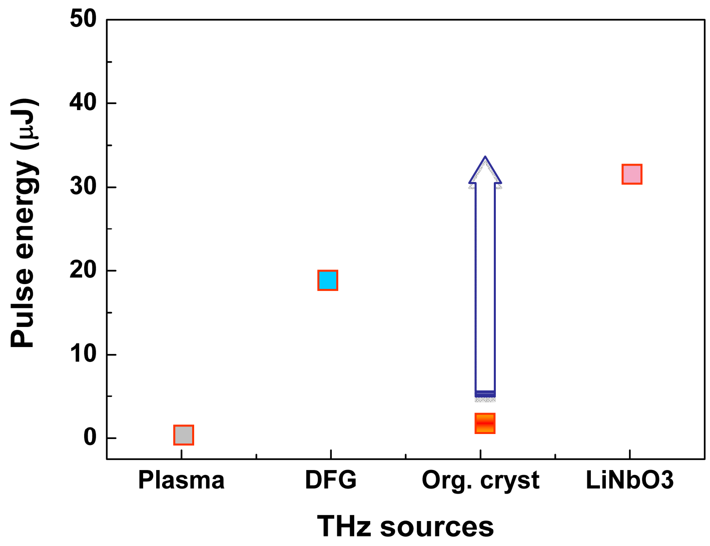
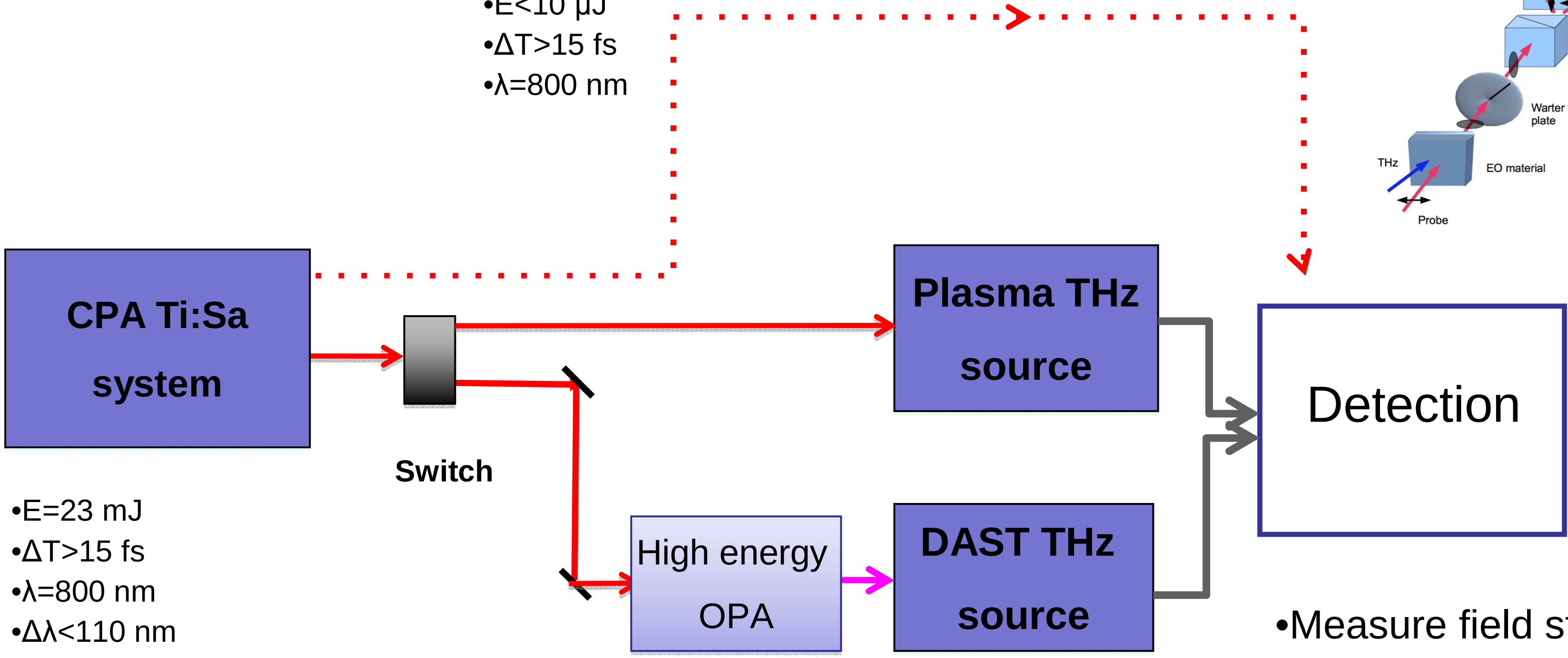
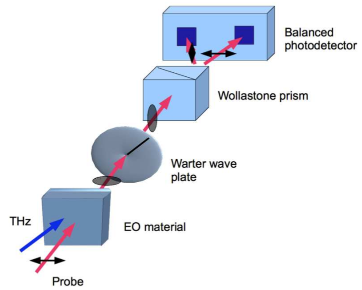


Laser-based THz generation - overview

- E<10 µJ
- ΔT>15 fs
- λ=800 nm





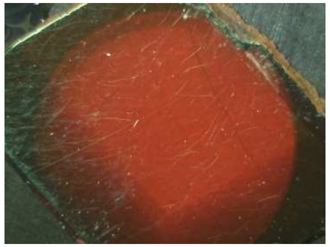
- E=23 mJ
- ΔT>15 fs
- λ=800 nm
- Δλ<110 nm
- 100 Hz

- E<3 mJ
- ΔT=65 fs
- λ=1.2-1.6 µm
- 100 Hz

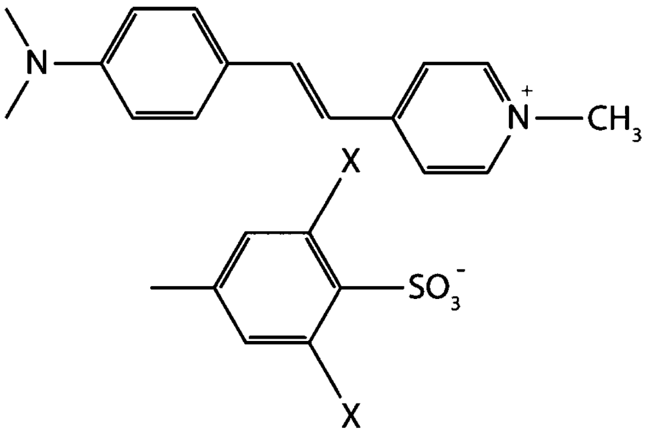
- Measure field strength
- Electric field
- Energy
- Transverse distribution

THz generation in stilbazolium salt crystals

- Highest THz generation efficiency for optical rectification
  - Organic crystals: ≈1% conversion efficiency
  - Inorganic: ≈ 0.1% conversion efficiency
- Velocity matched THz generation for telecom λ
- Collinear pump and THz output
- Intrinsically CEP stable
- Crystal types differ in THz absorption
  - => crystal according to requested THz range



DAST crystal

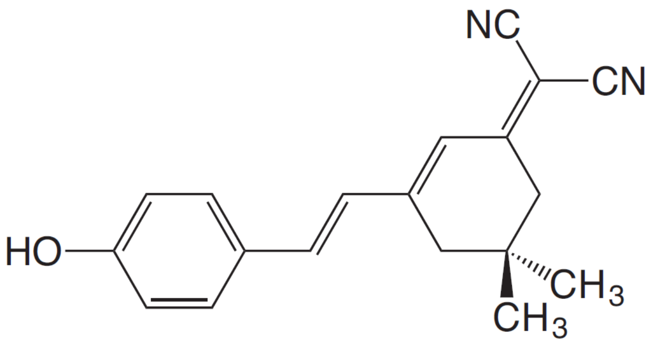


Chemical structure

DAST: X = H

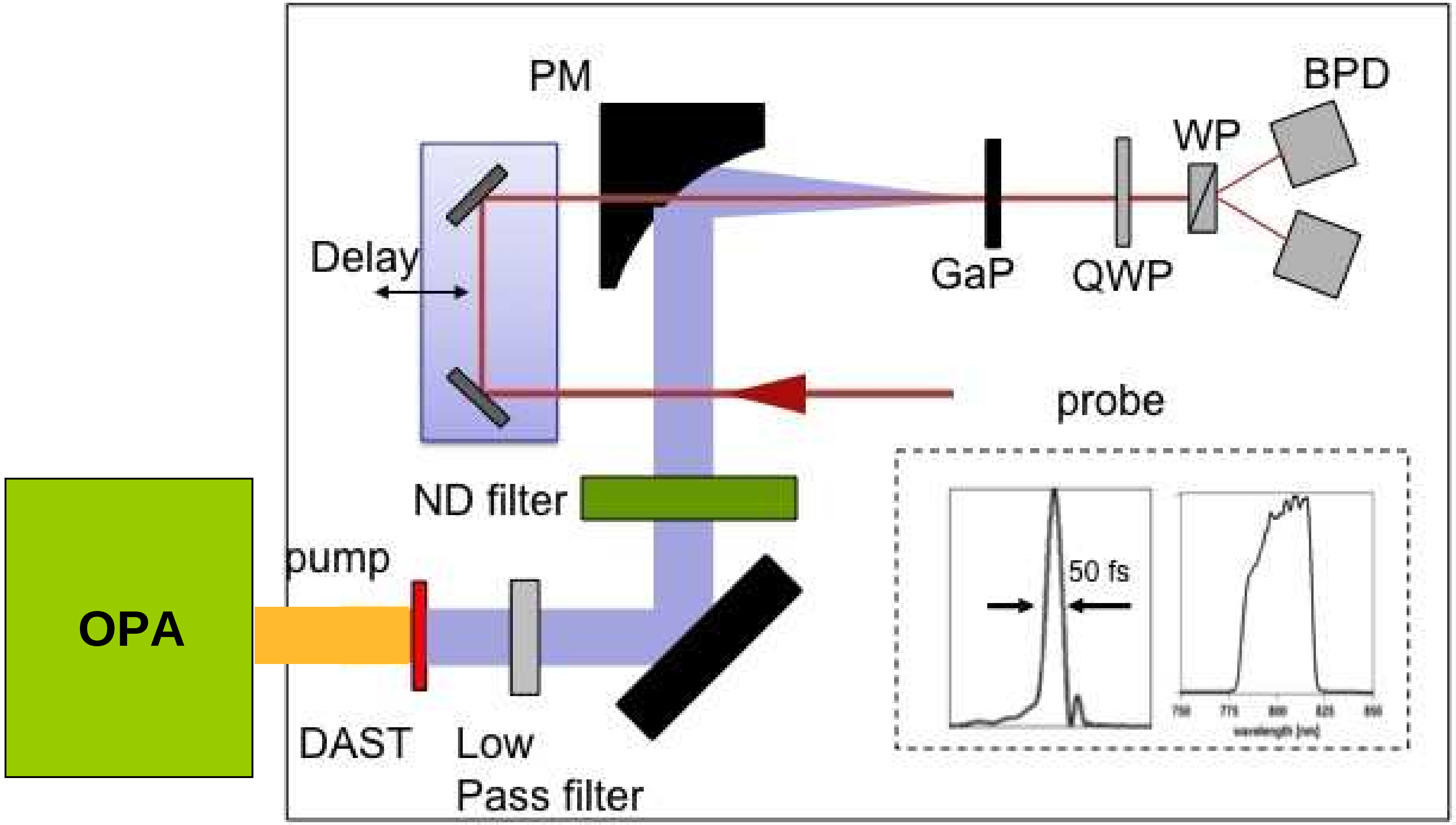
$C_{23}H_{26}N_2O_3S$

DSTMS: X = CH_3

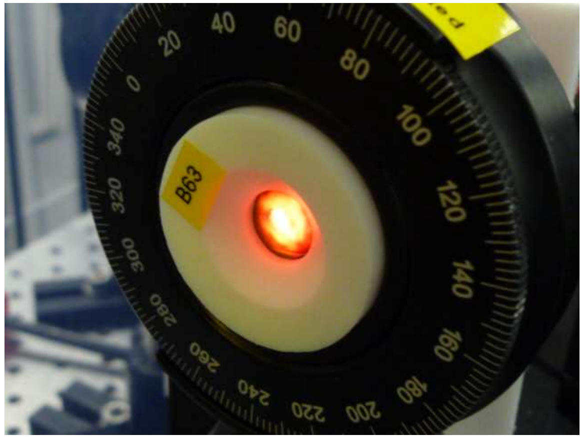


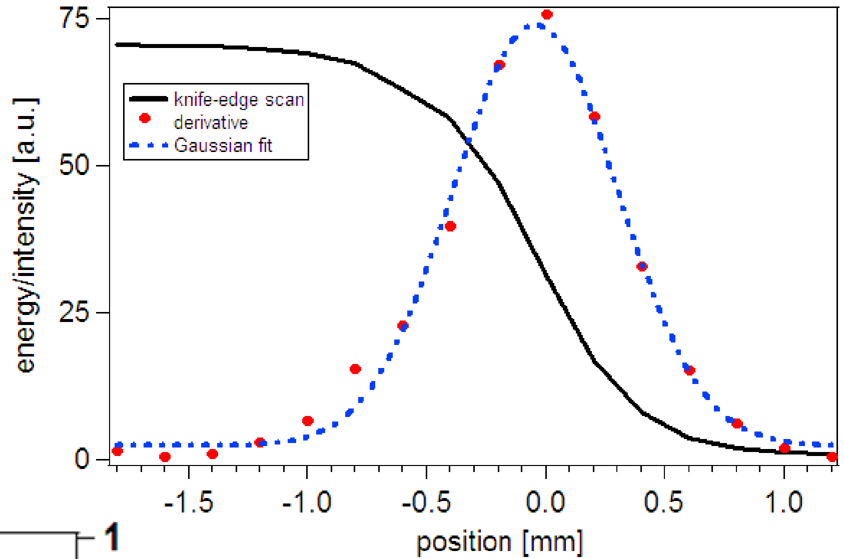
Chemical structure OH1

THz generation in stilbazolium salt crystals

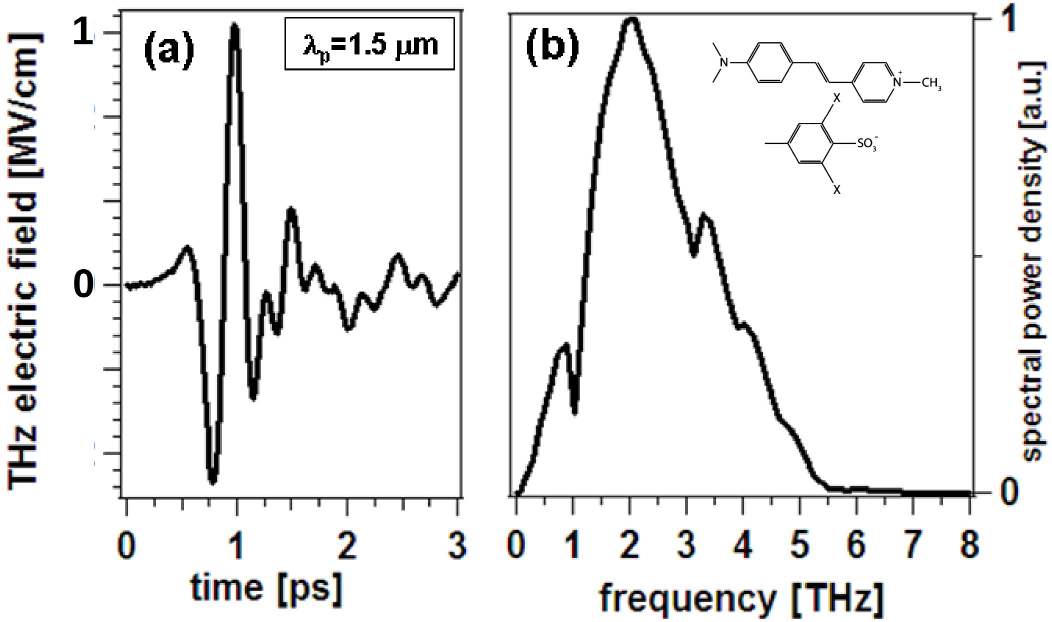


High power THz from organic crystals - DAST





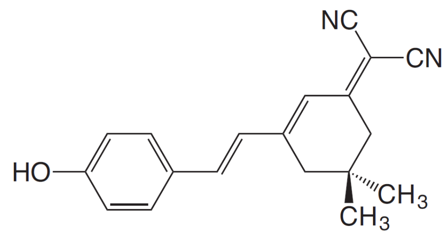
focus spot size

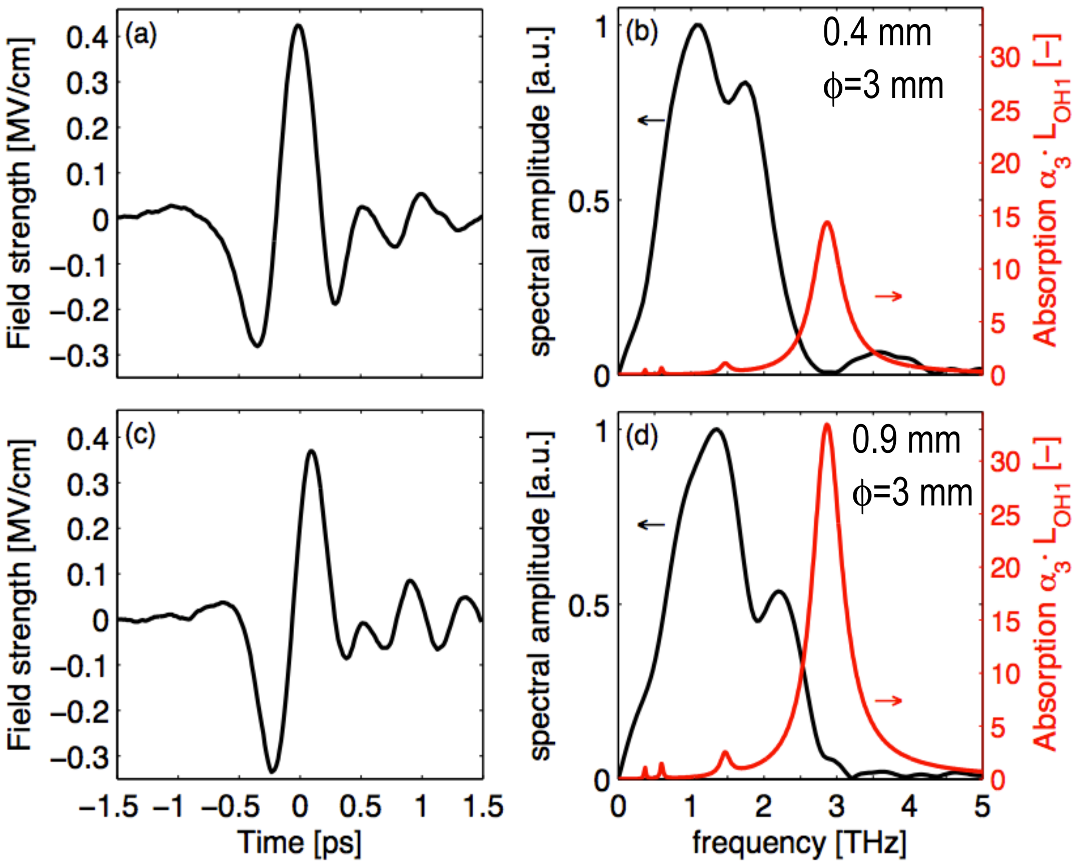


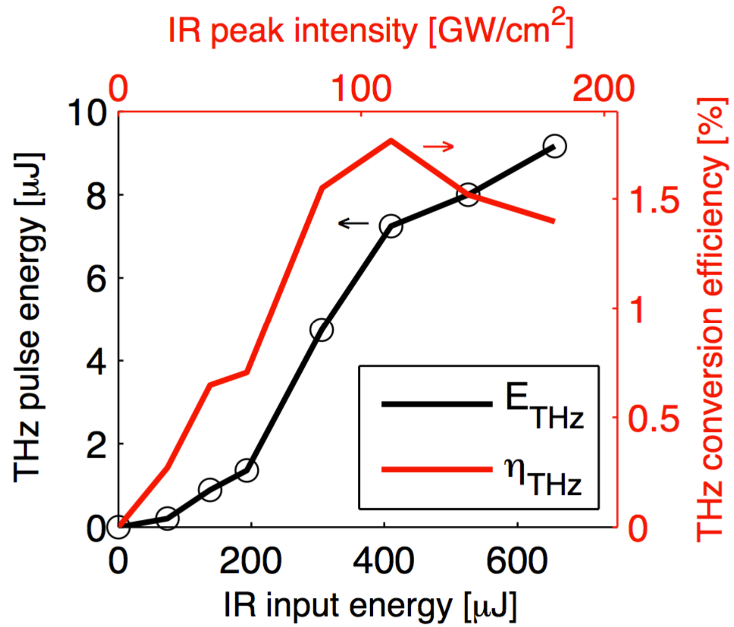
- good focusability
- >MV/cm
- ν_c= 2.3 THz
- broadband (up to 5 THz)
- close to single cycle

Hauri et al, Appl. Phys. Lett. 99, 161116, (2011)

High power THz from organic crystals – OH1





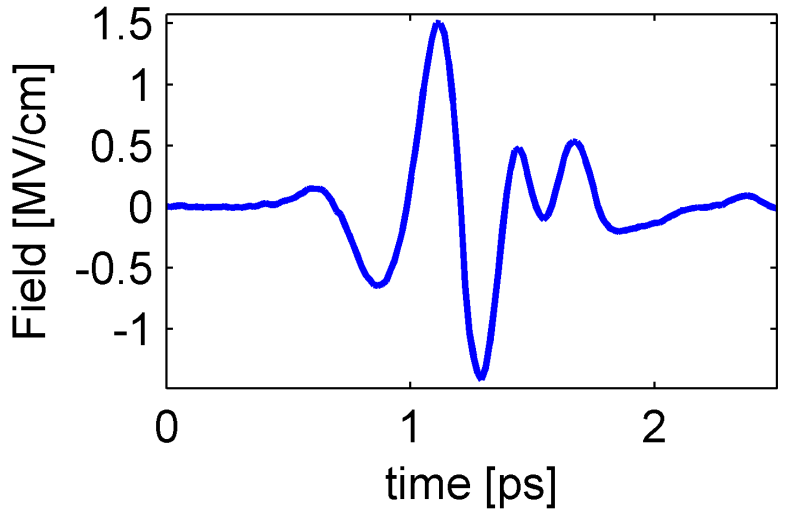


Ruchert et al Opt. Lett. 37, 5 (2012)

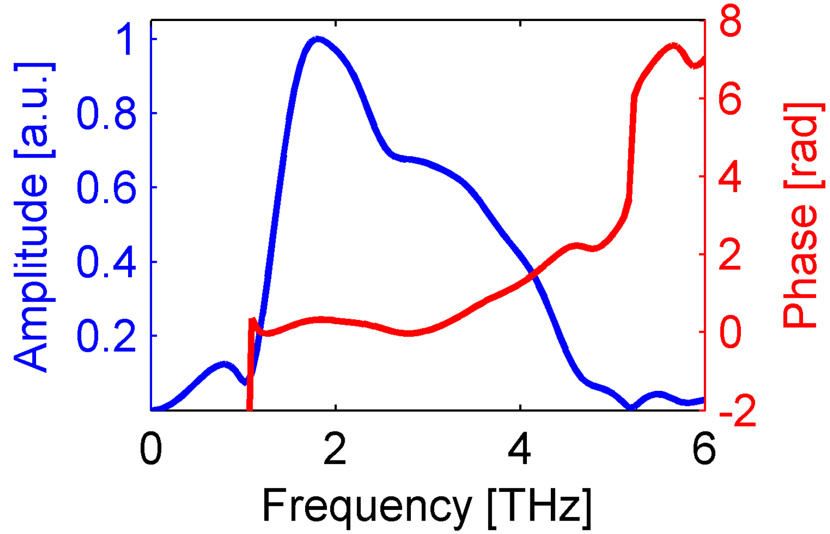
Hauri et al, Appl. Phys. Lett. 99, 161116, (2011)

High power THz from organic crystals – DSTMS

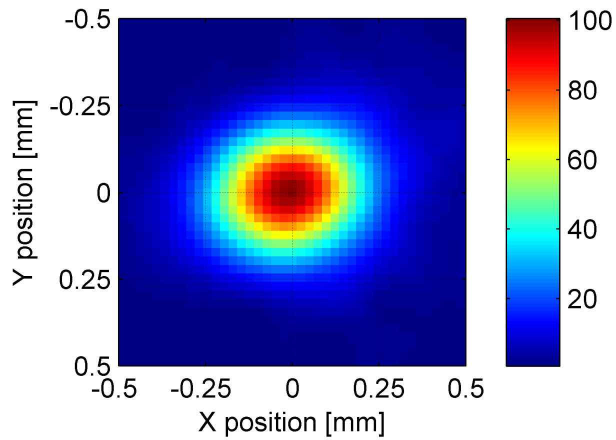
EOS field trace



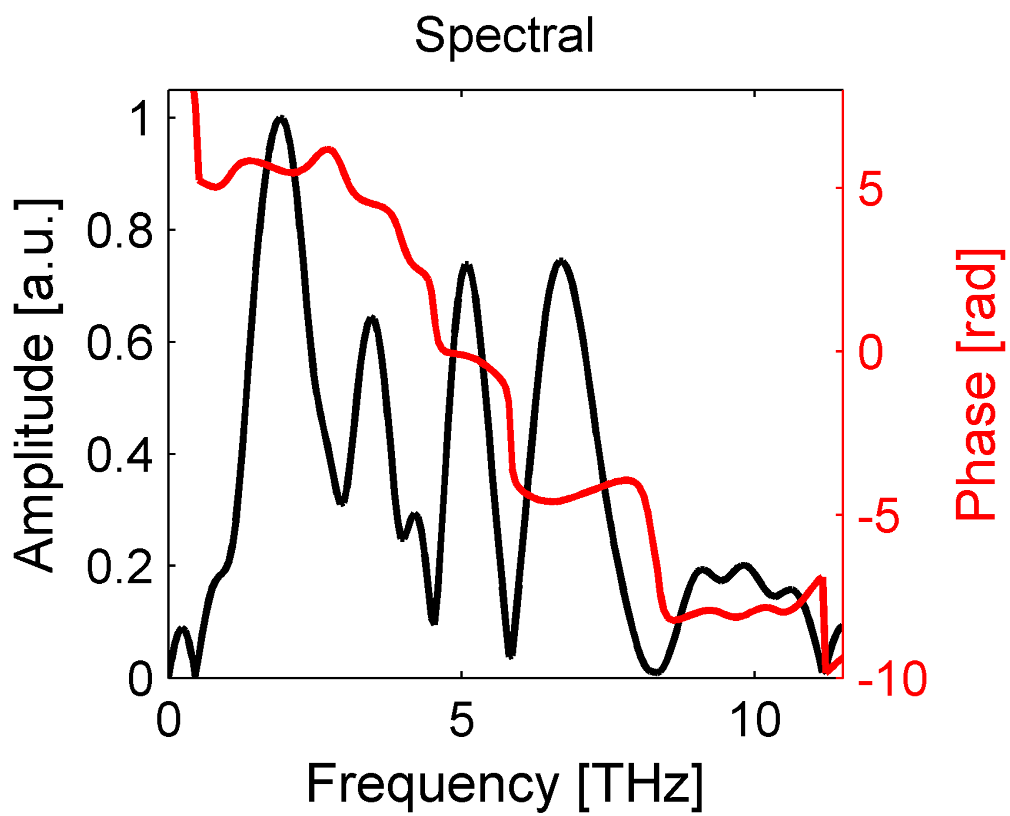
Spectrum

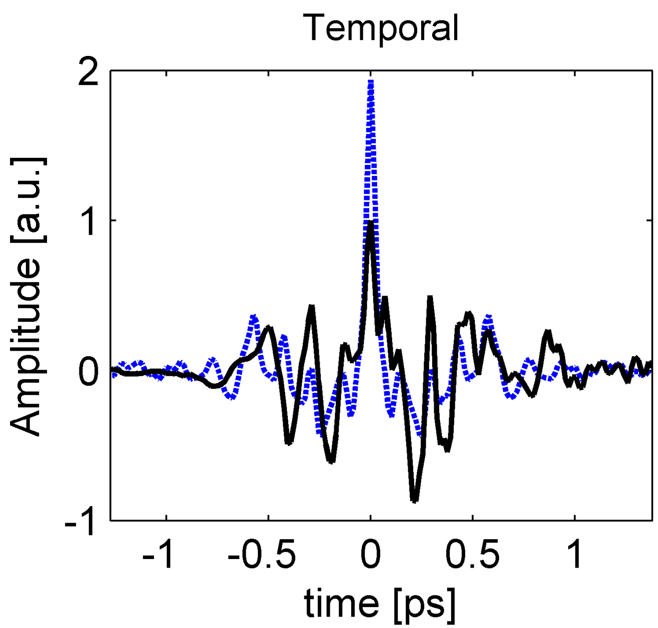


- Thickness: 0.49 mm
- Free aperture: 9 mm
- Pump energy: 2 mJ
- Peak field THz: 1.5 MV/cm
- Central frequency: 2.65 THz
- THz focus waist: 0.3 mm
- Diffraction limit: 0.27 mm



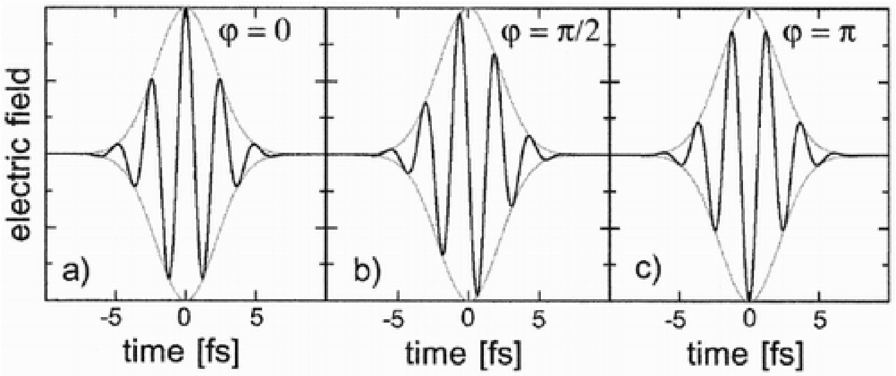
DSTMS – recent results





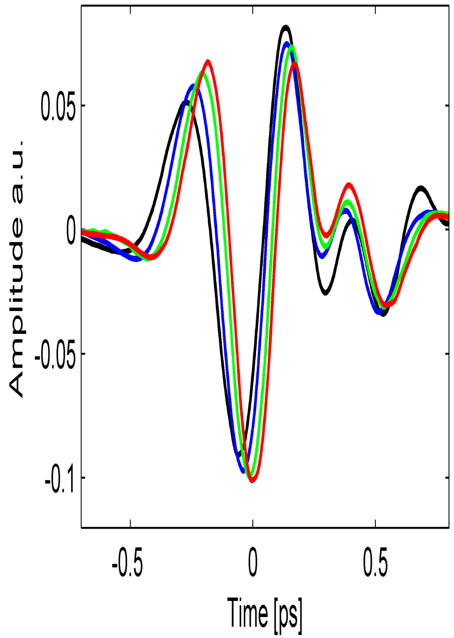
- limited by diagnostics and pump laser
- half-cycle pulse feasible

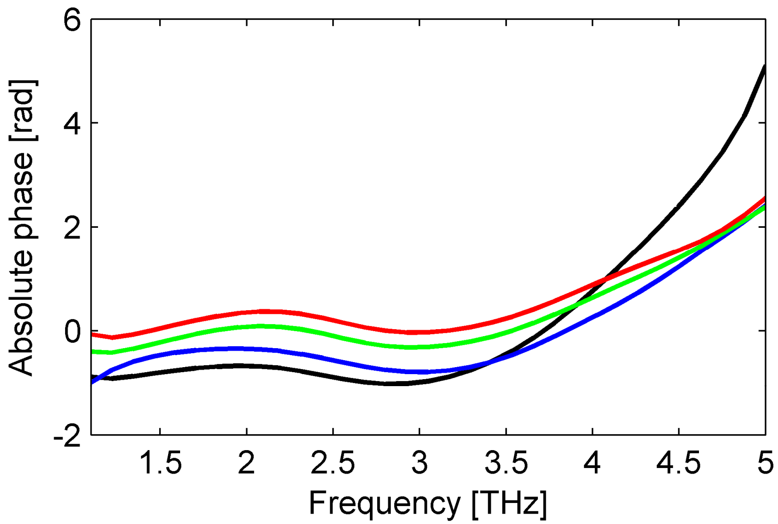
Towards absolute phase control



$$\Delta\varphi = \omega d\left(\frac{1}{v_{phase}} - \frac{1}{v_{group}} \right)$$

$$v_{group} = \frac{c}{n} + \frac{c\lambda}{n^2}\frac{\partial n}{\partial \lambda}$$





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Content

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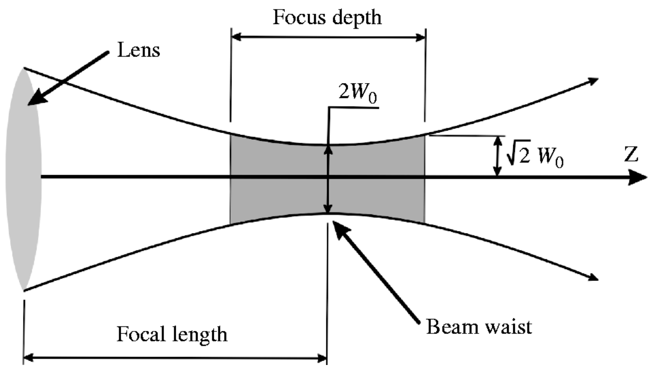
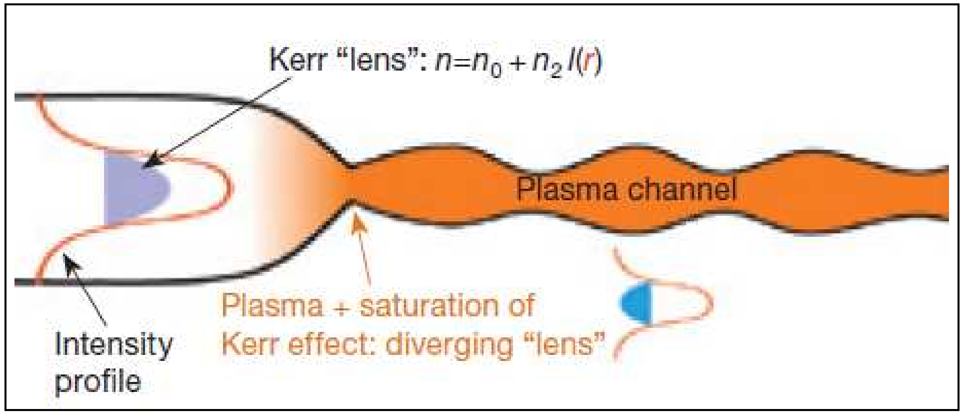
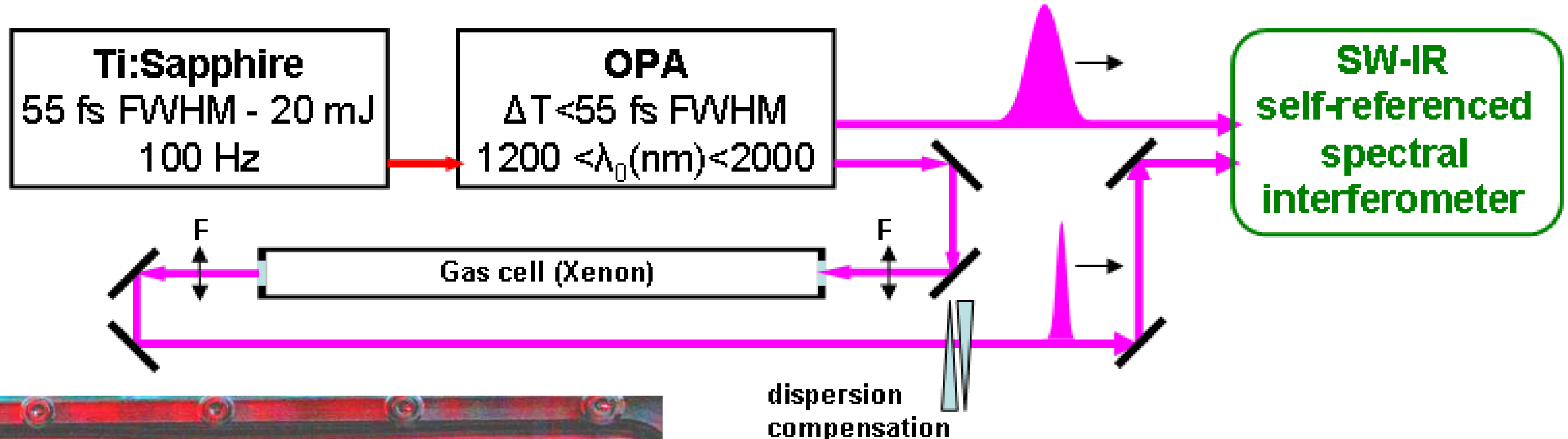
- **Frontend laser system**
- **Terahertz laser** — Organic crystal as optical rectifier; broadband, single cycle pulses; carrier-envelope phase control
- **Infrared few cycle pulses** — NL pulse compression by filamentation
- **Implementation at SwissFEL endstation**
- **HHG beamline at PSI** — Seeding towards shorter wavelengths
- **Conclusion**

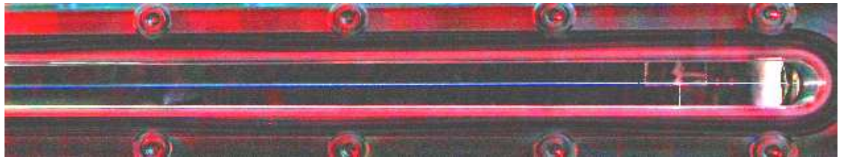
IR pulse compression by filamentation





Self-broadening and self-compression in Xe using 65 fs OPA output

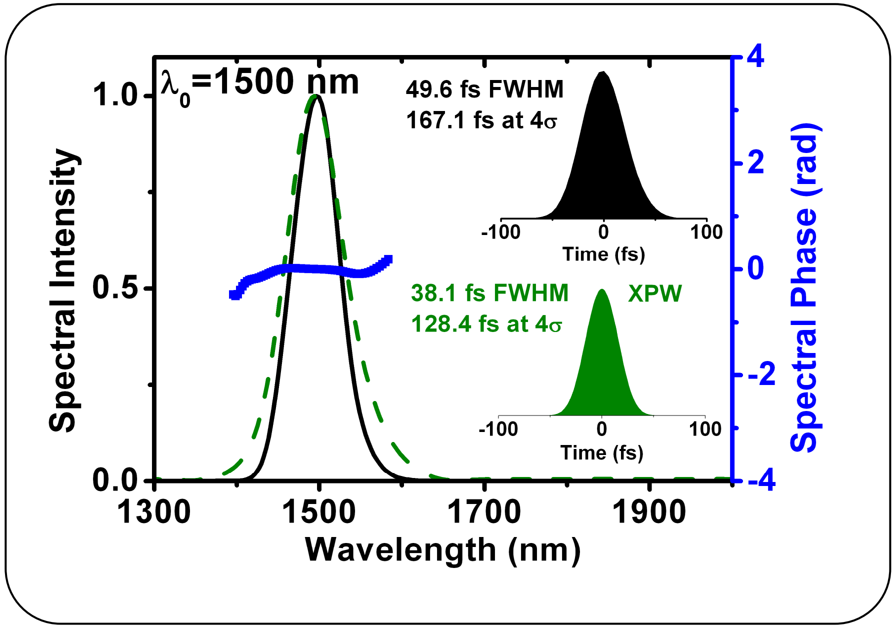




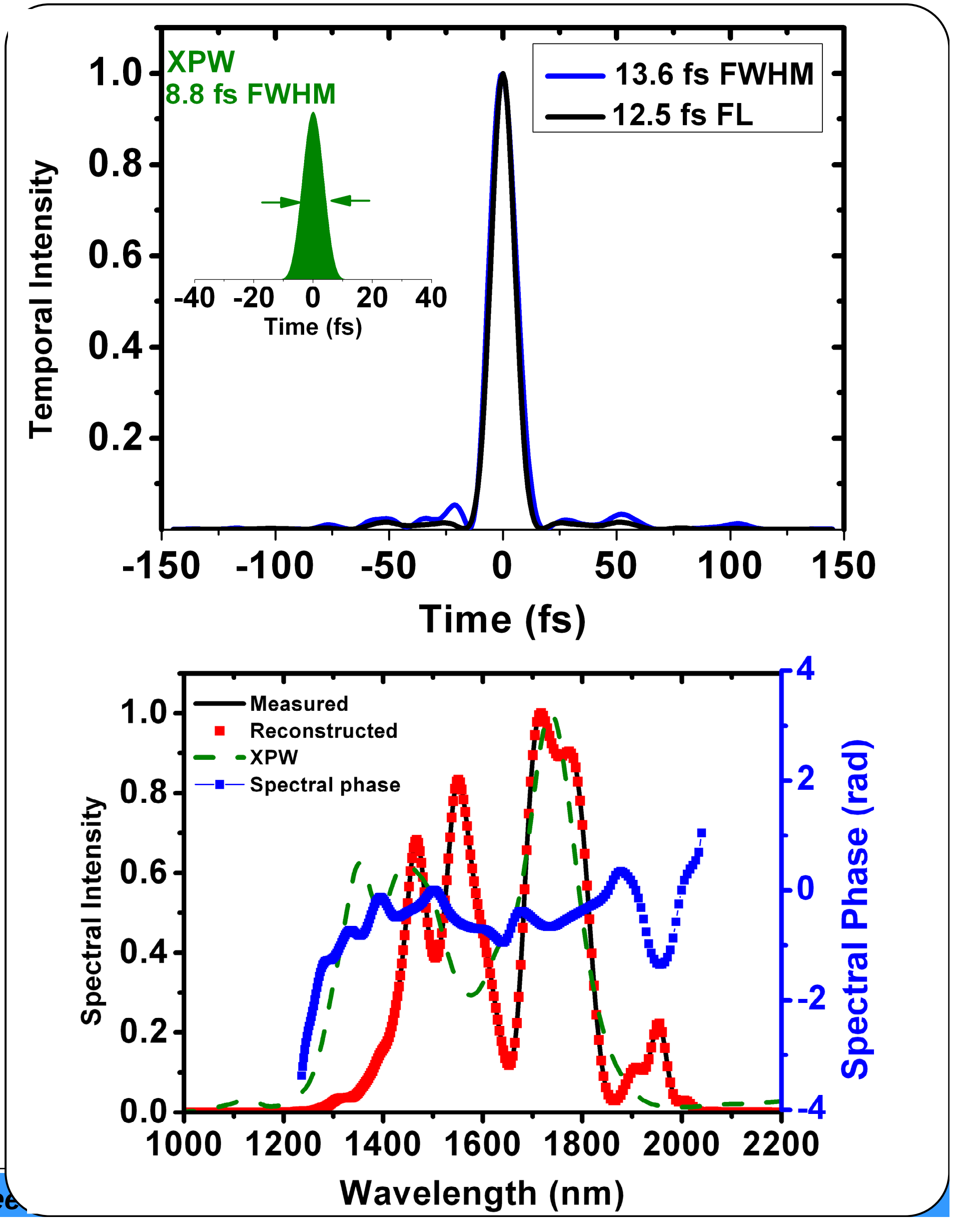
Trisorio et al Opt. Lett. 37, 2982 (2012)

Infrared pulse compression

before filament



after filament



- *spectral broadening*
- *temporal pulse compression*
- *≈2 optical cycles, 1.2 mJ*

Applications:

- short probe for PP measurements
- EO sampling at high resolution for THz
- Potential for pumping THz

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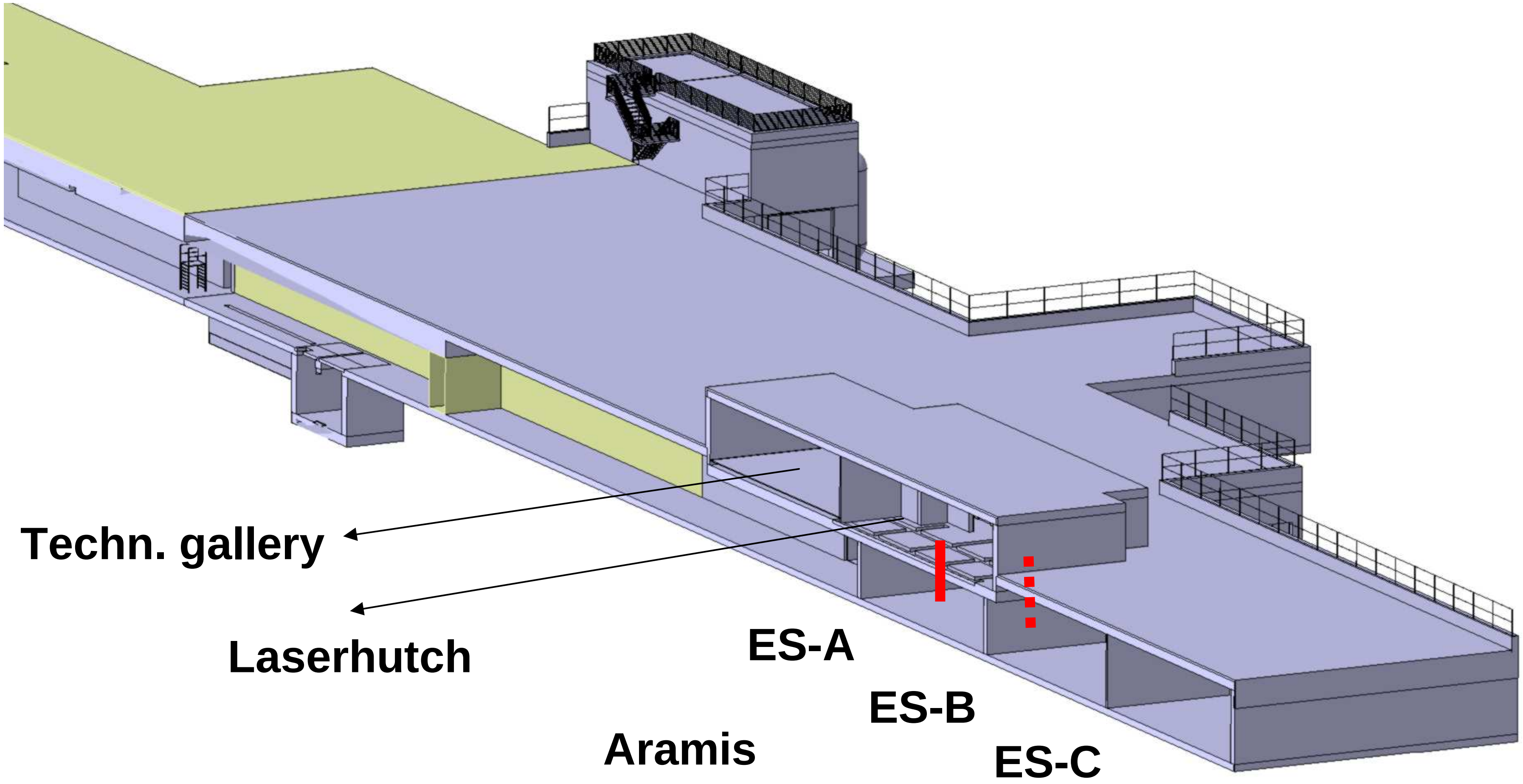
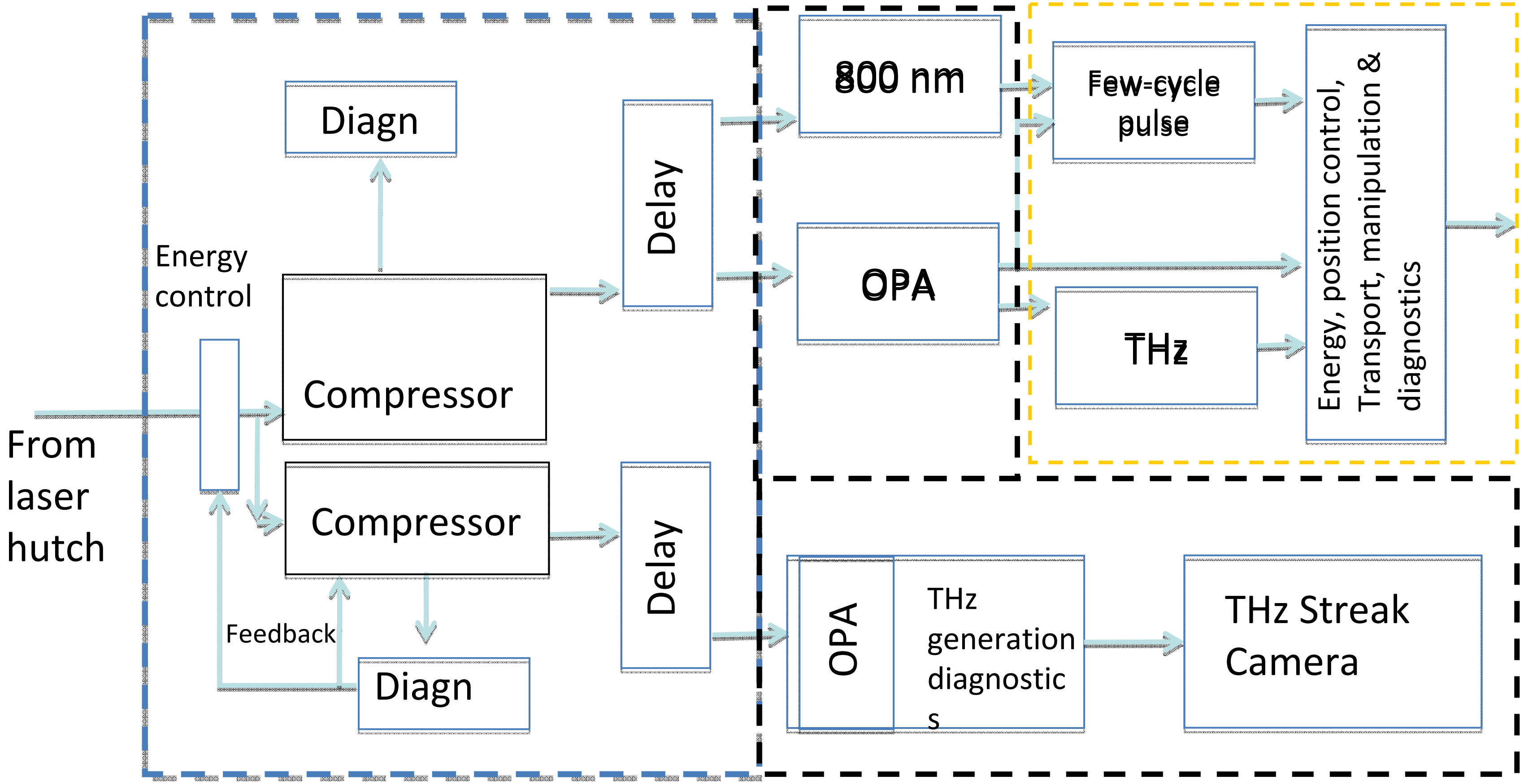
Lasers at the SwissFEL Aramis endstations



Lasers at the SwissFEL endstations



- separate dispersive line for experiment and diagnostics
- online beam arrival time monitor at experiment
- in nearest neighborhood to endstation

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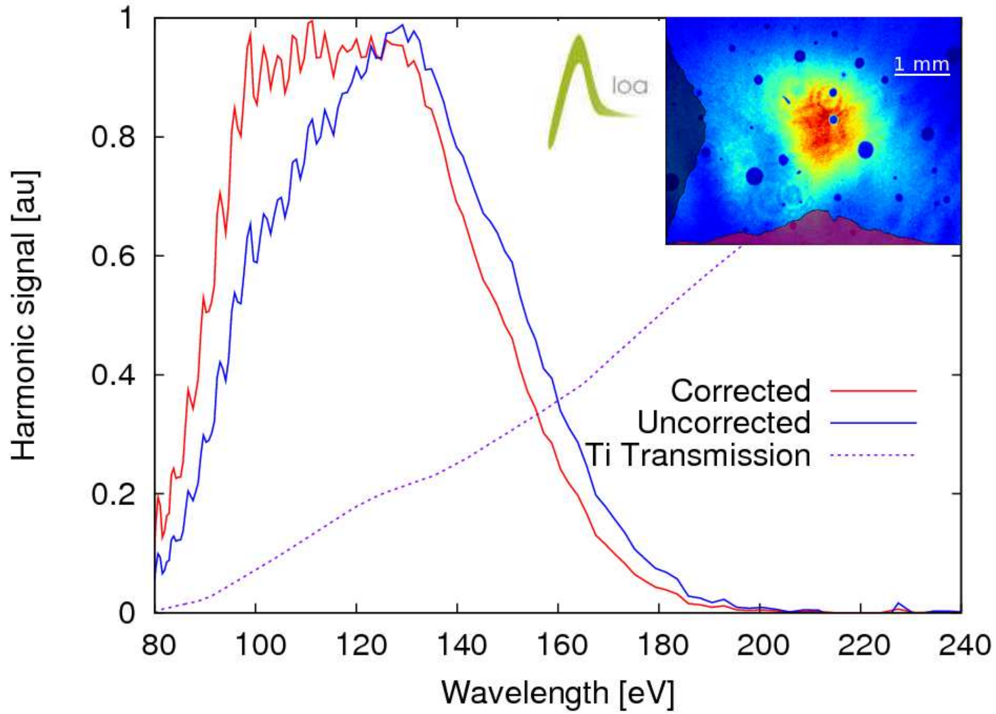
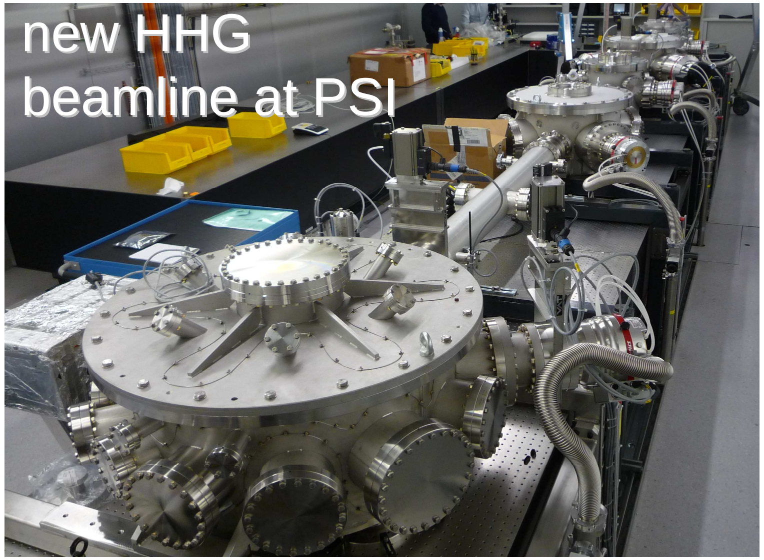
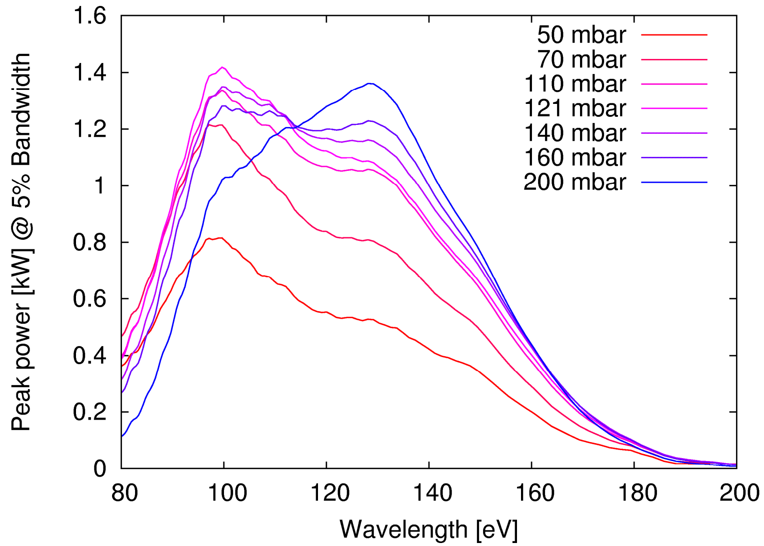
HHG development – towards seeding at short λ

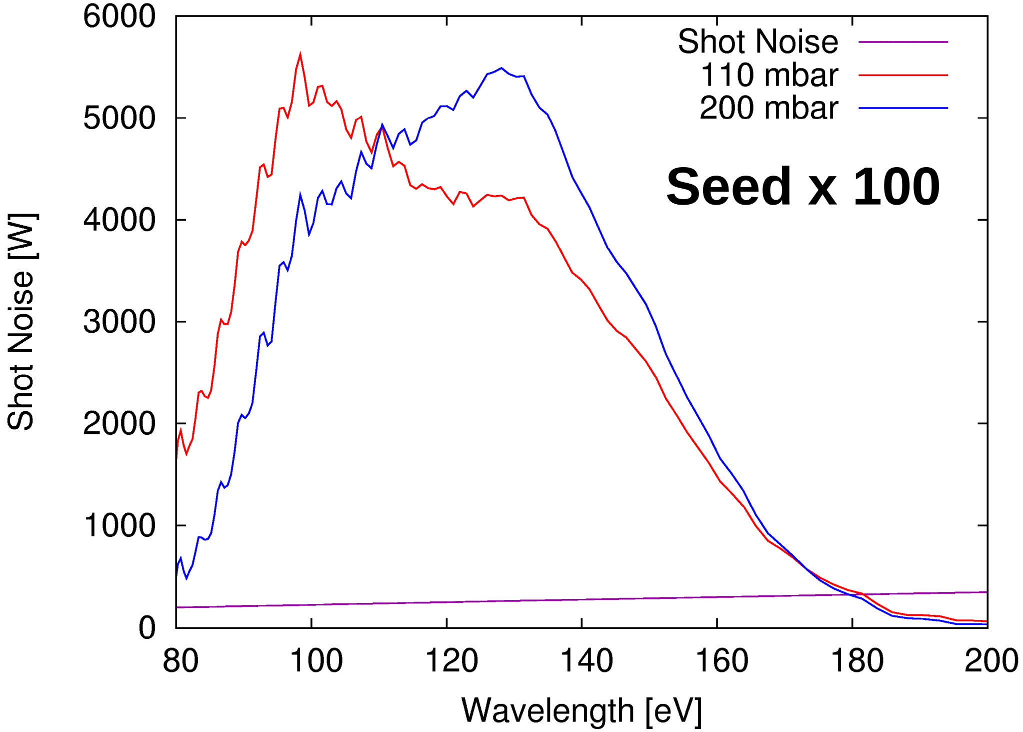




- PM in capillary up to 8.8nm (140 eV)
- E_{laser} 1 mJ in capillary
- 1 kW in 5% BW @ 140 eV (TL)
- improvements required for seeding (peak power, cutoff extension)



HHG beamline – scaling seed power

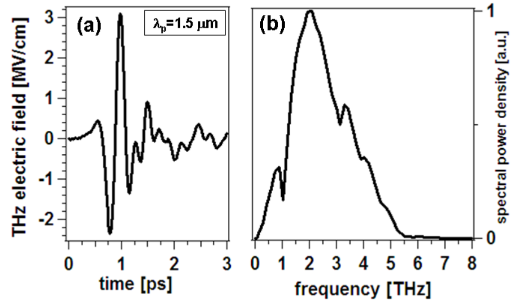


FEL parameters (≈Athos)

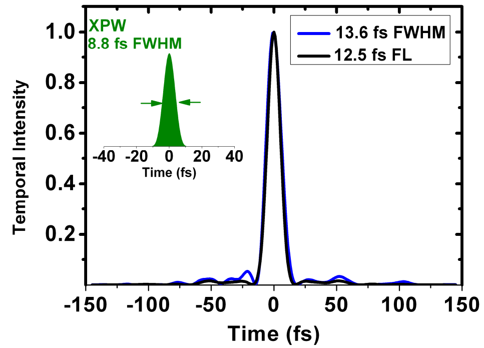
ε_n=0.4 mm mrad
β=10.647 m
K_0=1
I_{peak}=2.7e3 A
ΔE=0.35 MeV energy spread
E_0=2.4 GeV
40 mm undulator period

Conclusion

- developed new approach for high power, single cycle THz pulses based on organic crystals (1-10 THz, up to 1.5 MV/cm, 0.5 Tesla)



- Few-cycle pulse generation by nonlinear pulse compression @ 1.5 µm



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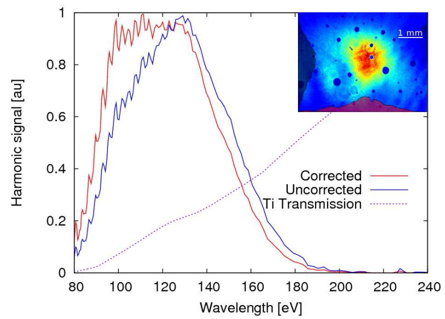
- HHG developments towards seeding at shorter wavelengths



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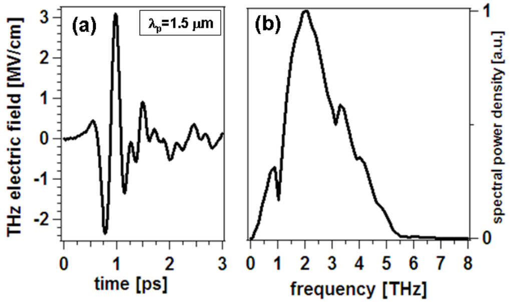

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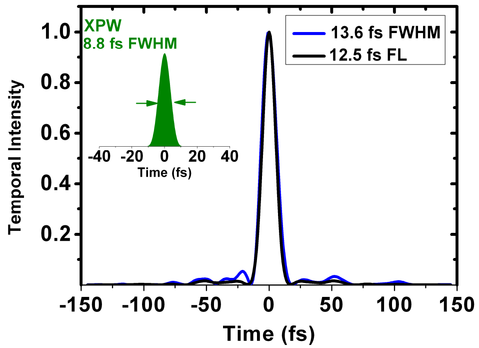

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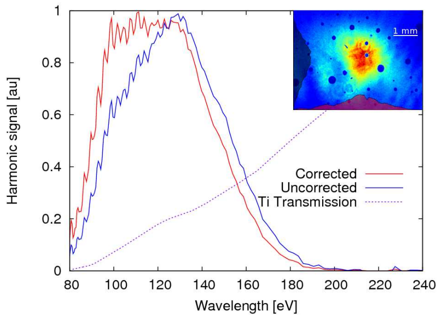

Thank you for your attention