Collinear and Non-Collinear Second Harmonic Generation in BBO Crystal.

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Non-linear optics

- Low intensities of electric field

$$P(t) = \varepsilon_0 \chi^{lin} E(t)$$

- Very high intensity of light

$$P(t) = P\{E(t)\}$$

Several non-linear effects appears

Second harmonic generation	(SHG)
Third harmonic generation	(THG)
High harmonic generation	(HHG)
Sum frequency generation	(SFG)
Optical parametric generation	(OPG)
…	

Goal of the project

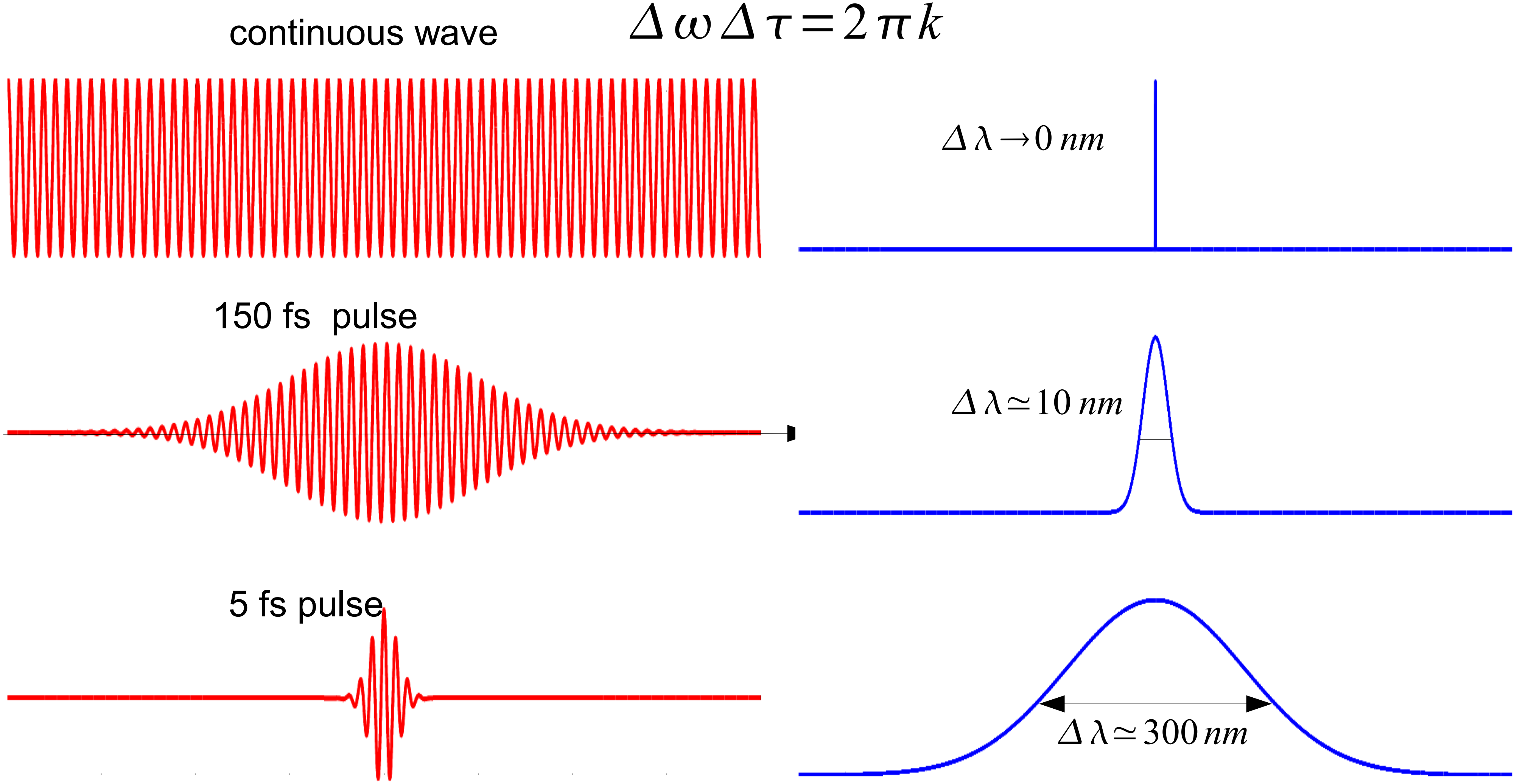
- To use nonlinear processes for frequency conversion of the broadband fs pulses

- Find the best configuration for broadband SHG
- Determine spectral limits for common non-linear crystals
- Both theoretical and experimental approach

Properties of ultra-short laser pulses

Electromagnetic wave | **Spectra**

$$\Delta\omega\Delta\tau = 2\pi k$$



Second harmonic generation

- Conservation of energy holds automatically

$$\omega_1 + \omega_1 = \omega_2$$

- Conservation of momentum implies a necessary condition:

$$\vec{k}_1 + \vec{k}_1 = \vec{k}_2$$

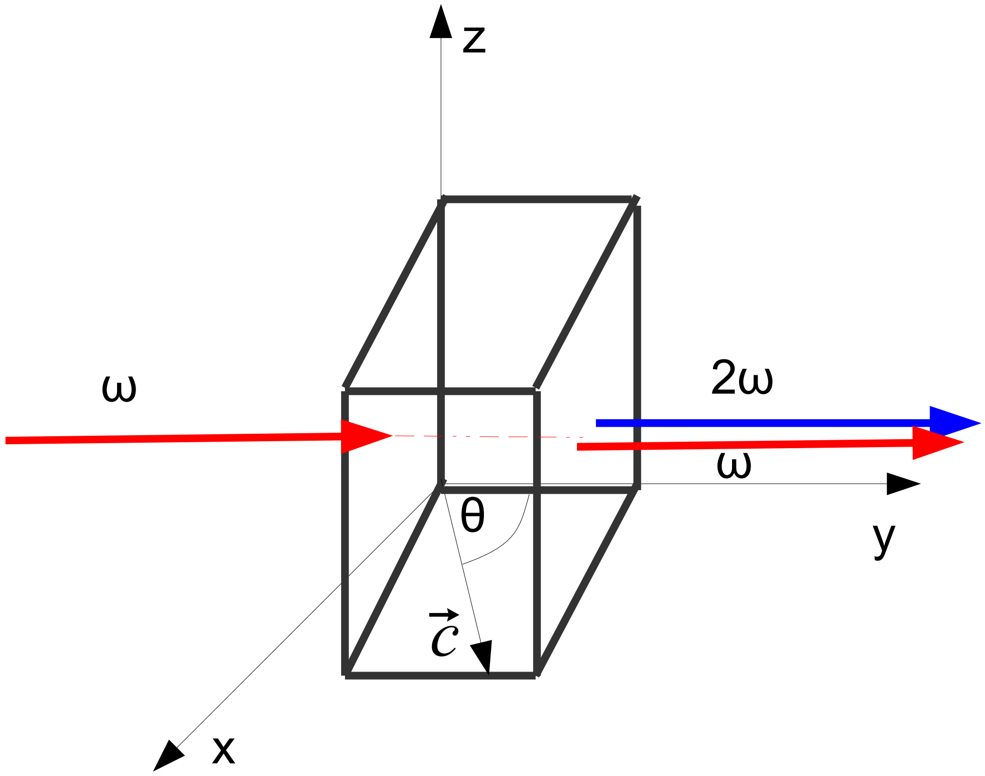
Phase velocities of fundamental beam and second harmonic have to be synchronized

$$\vec{v}_f(\omega_1) = \vec{v}_f(\omega_2)$$
$$n(\omega_1) = n(\omega_2)$$

Possible only in the birefringent crystals

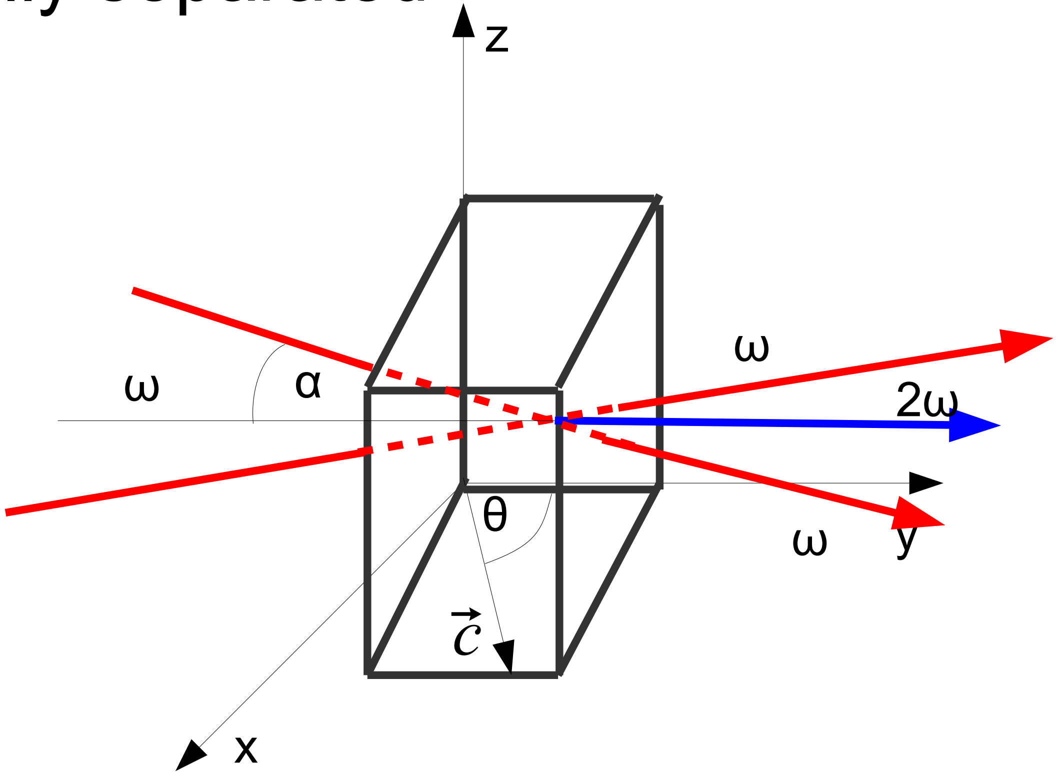
Collinear second harmonic generation (SHG)

- The only one incoming fundamental beam
- Simple geometry
- The rest of fundamental beam has to be filtered



Non-collinear second harmonic generation

- We can choose non-collinear angle α in order to optimize SHG
- The fundamental beam and the second harmonic are automatically separated



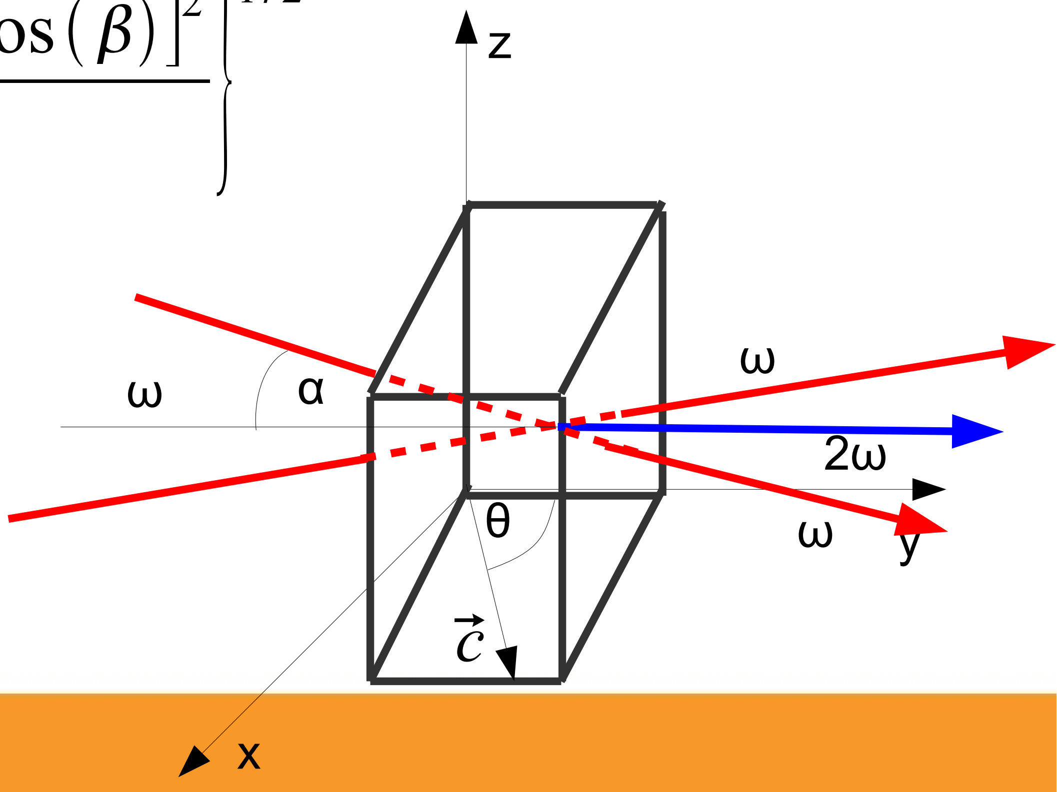
Theoretical approach

$$I_{2\omega}(l)=\frac{32\pi^3\omega^2}{c^3 n^2(\omega)n(2\omega)}\left|\hat{e}(2\omega)\hat{\chi}^{(2)}(2\omega):\hat{e_\omega}\hat{e_\omega}\right| l^2\left[\frac{\sin(\Delta k\, l/2)}{\Delta k\, l/2}\right]^2 I_\omega^2(0)$$

$$\sin(\theta_{pm})=\frac{n_e(\lambda_c)}{\eta_o(\lambda_b)\cos(\alpha)+\eta_o(\lambda_a)\cos(\beta)}$$

$$\times\left\{\frac{\eta_o^2(\lambda_c)-[\eta_o(\lambda_b)\cos(\alpha)+\eta_o(\lambda_a)\cos(\beta)]^2}{n_o^2(\lambda_c)-n_e^2(\lambda_c)}\right\}^{1/2}$$

$$\beta=asin\left[\frac{\eta_o(\lambda_b)}{\eta_o(\lambda_a)\sin(\alpha)}\right]$$



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Results – collinear mode

λ = 786 nm:

- BBO

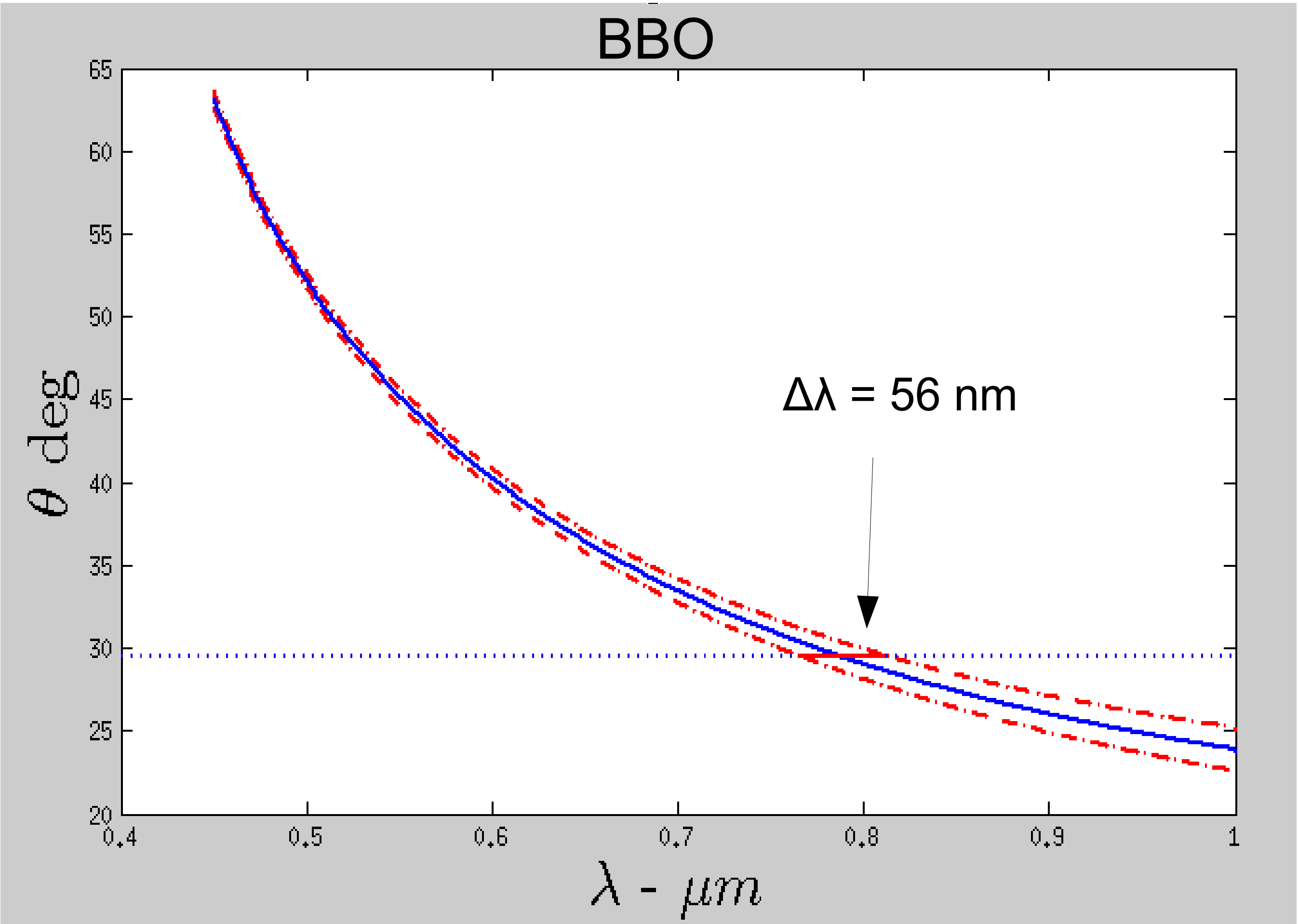
  $\Delta\lambda = 56$ nm

  $\Delta t \approx 40$ fs

- KDP

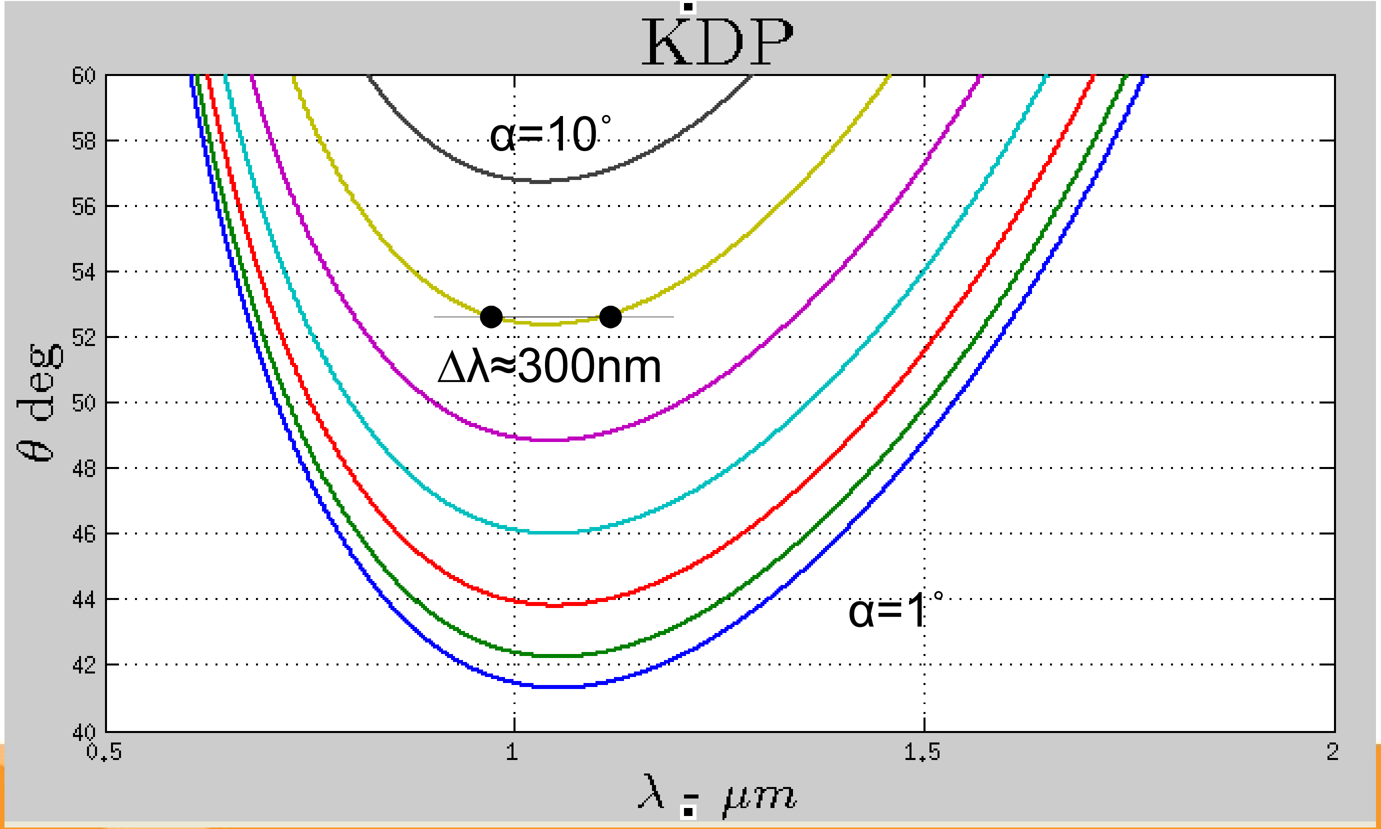
  $\Delta\lambda = 120$ nm

  $\Delta t \approx 20$ fs



Results – non-collinear mode

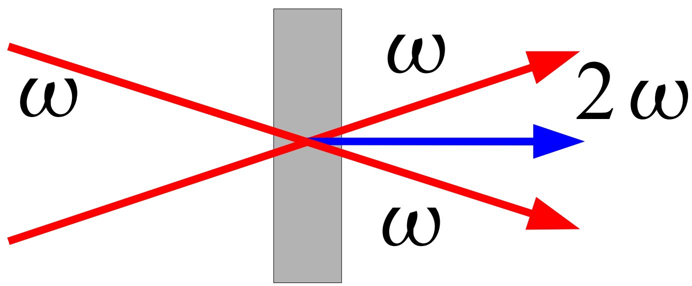
- Both BBO and KDP are suitable for broadband SHG in the near IR region
- Wavelength ideal for broadband SHG slowly varies with α.



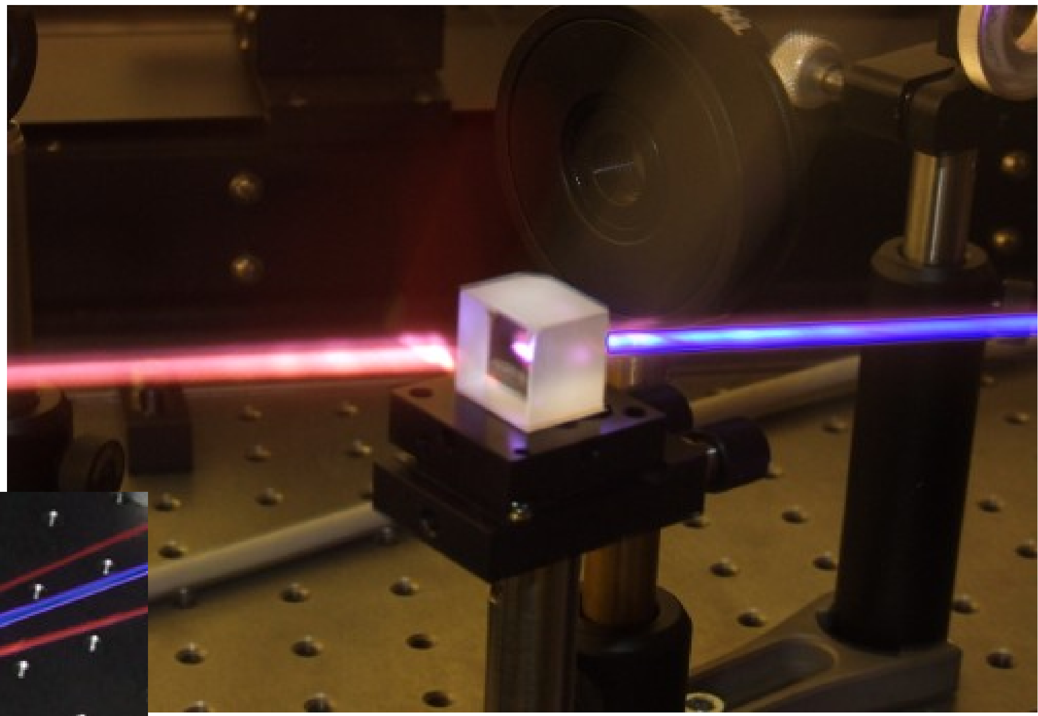
KDP
$\lambda_b \approx 1100$nm
BBO
$\lambda_b \approx 1500$nm
LBO
$\lambda_b \approx 1400$nm

Experimental results

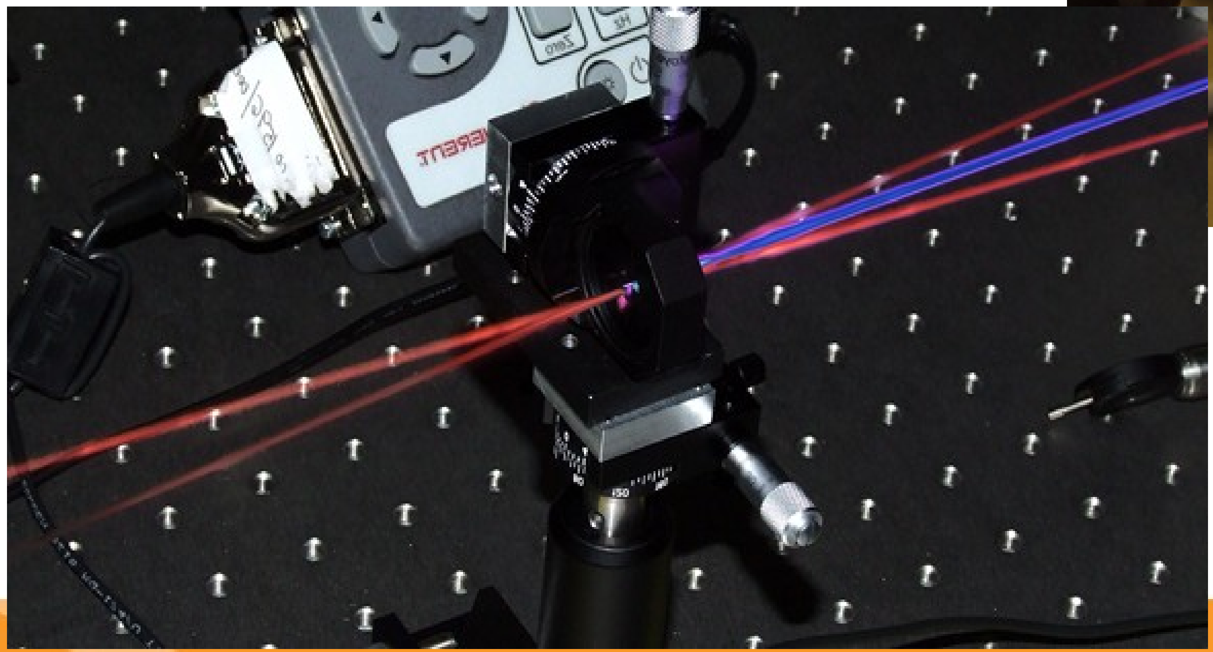
λ = 786nm

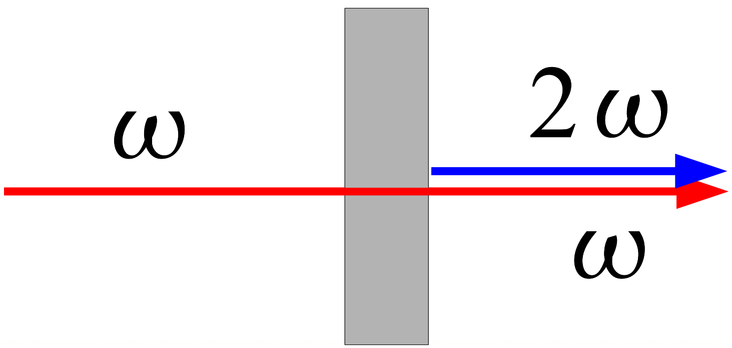


Collinear generation



Non-collinear generation

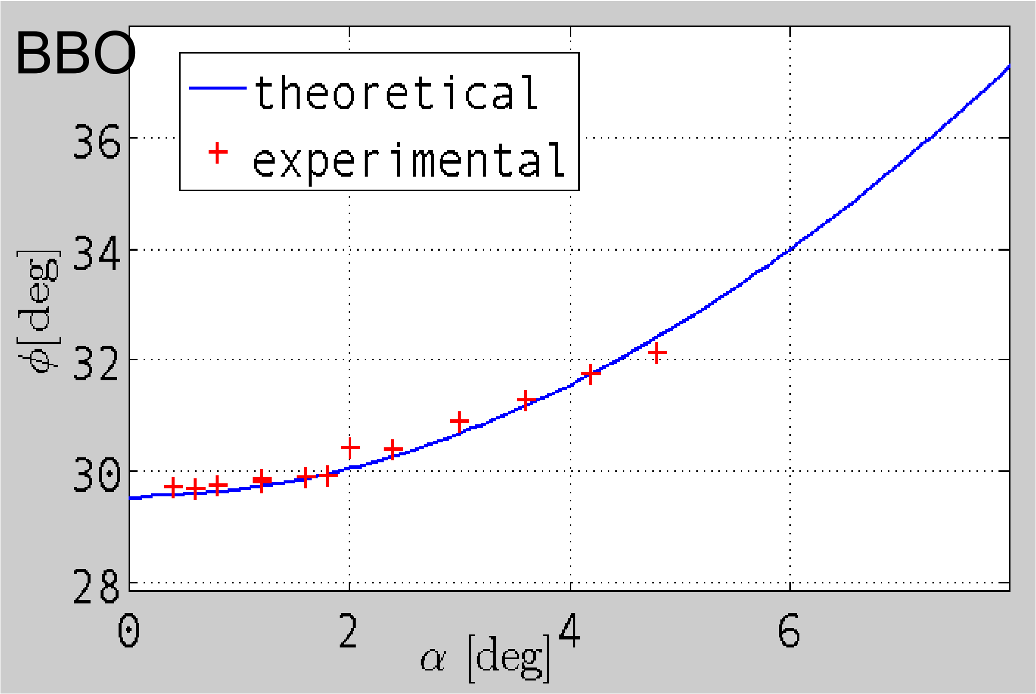




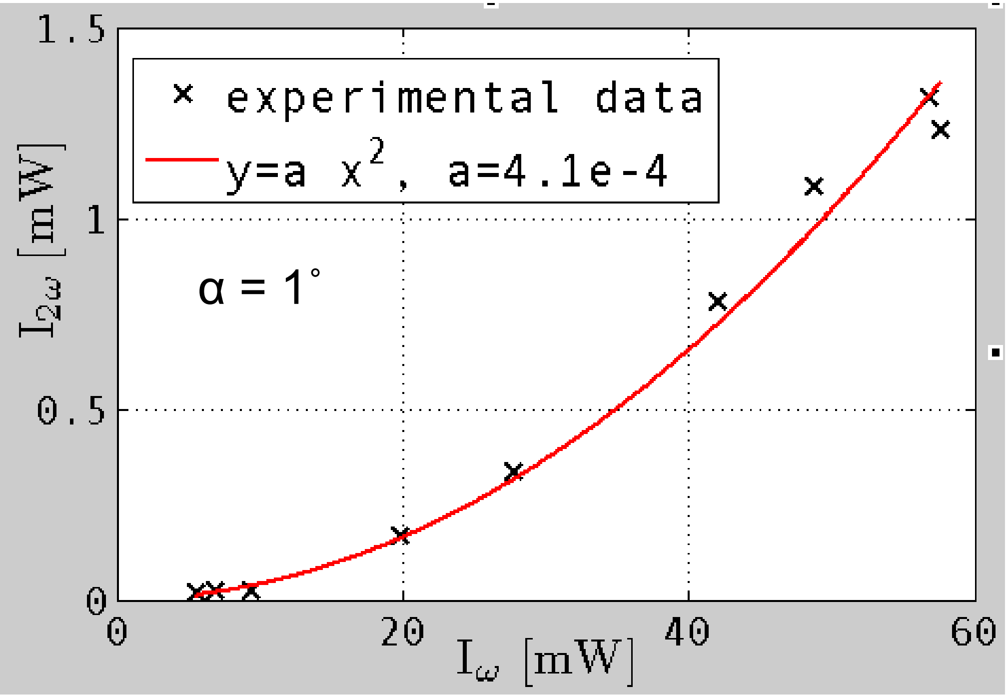
$$\eta_{max}=0.2$$

Non-collinear phase matching

Comparison of the theoretically calculated phase matching angle with the measured data



Power of the second harmonic depending on the power of the fundamental beam



SHG of ultra-short visible pulses

- BBO, LBO, KDP do not offer broadband SHG with a visible light.
- Possibilities:
  - try different nonlinear crystals
  - try different polarization of interacting beams
  - try different nonlinear process:

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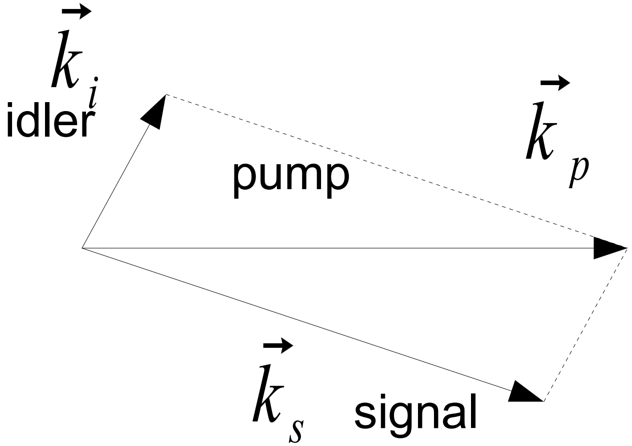
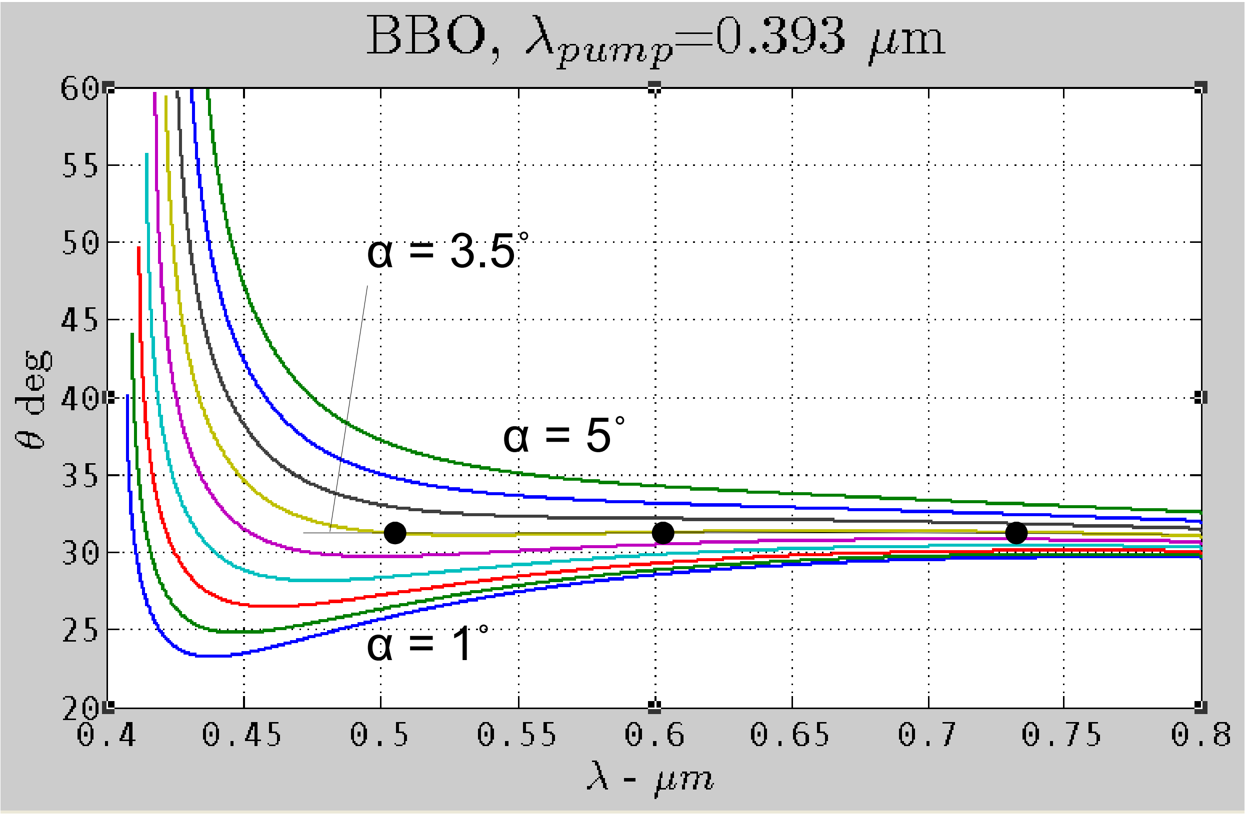
Other type of frequency conversion: Parametric processes

Optical parametric generation

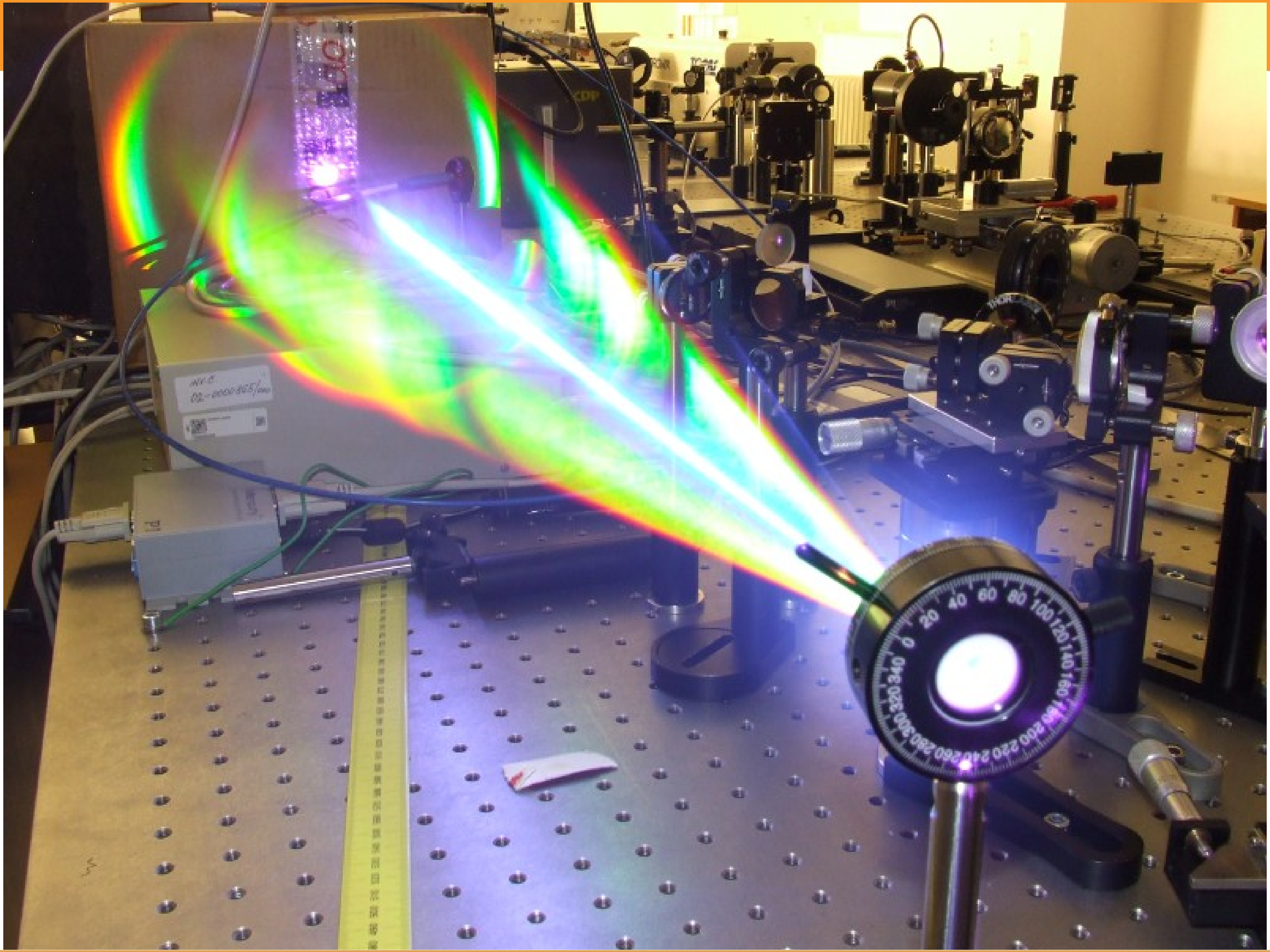


BBO, λp = 393nm:
Phase matching for α = 3.5˚:
Δλ ≈ 300nm, Δt ≈ 4fs.

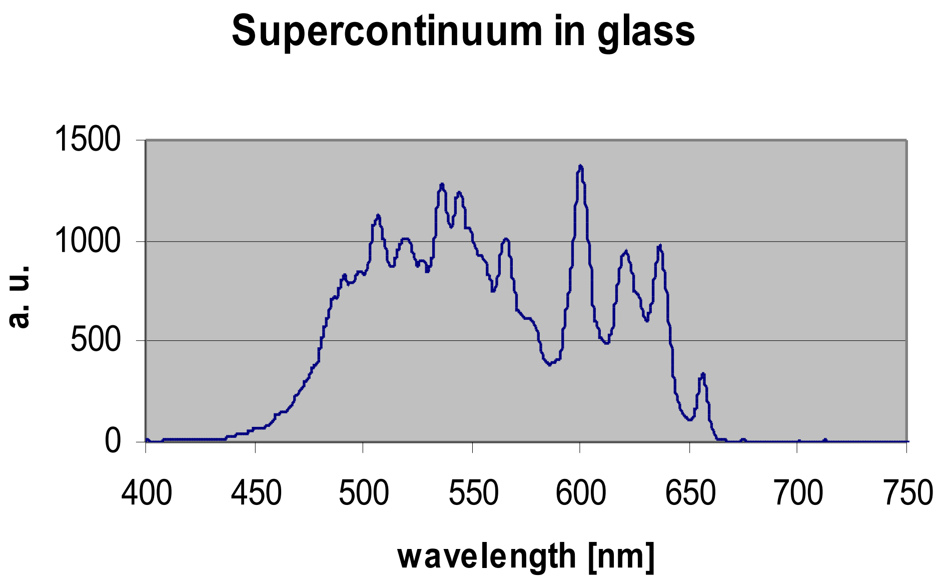
$$\vec{k}_p = \vec{k}_i + \vec{k}_s$$
$$\omega_p = \omega_i + \omega_s$$

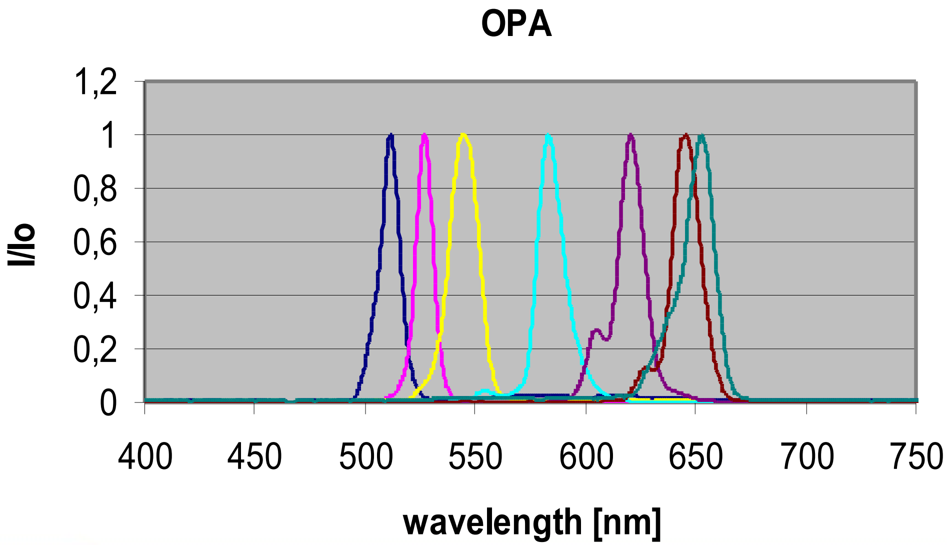


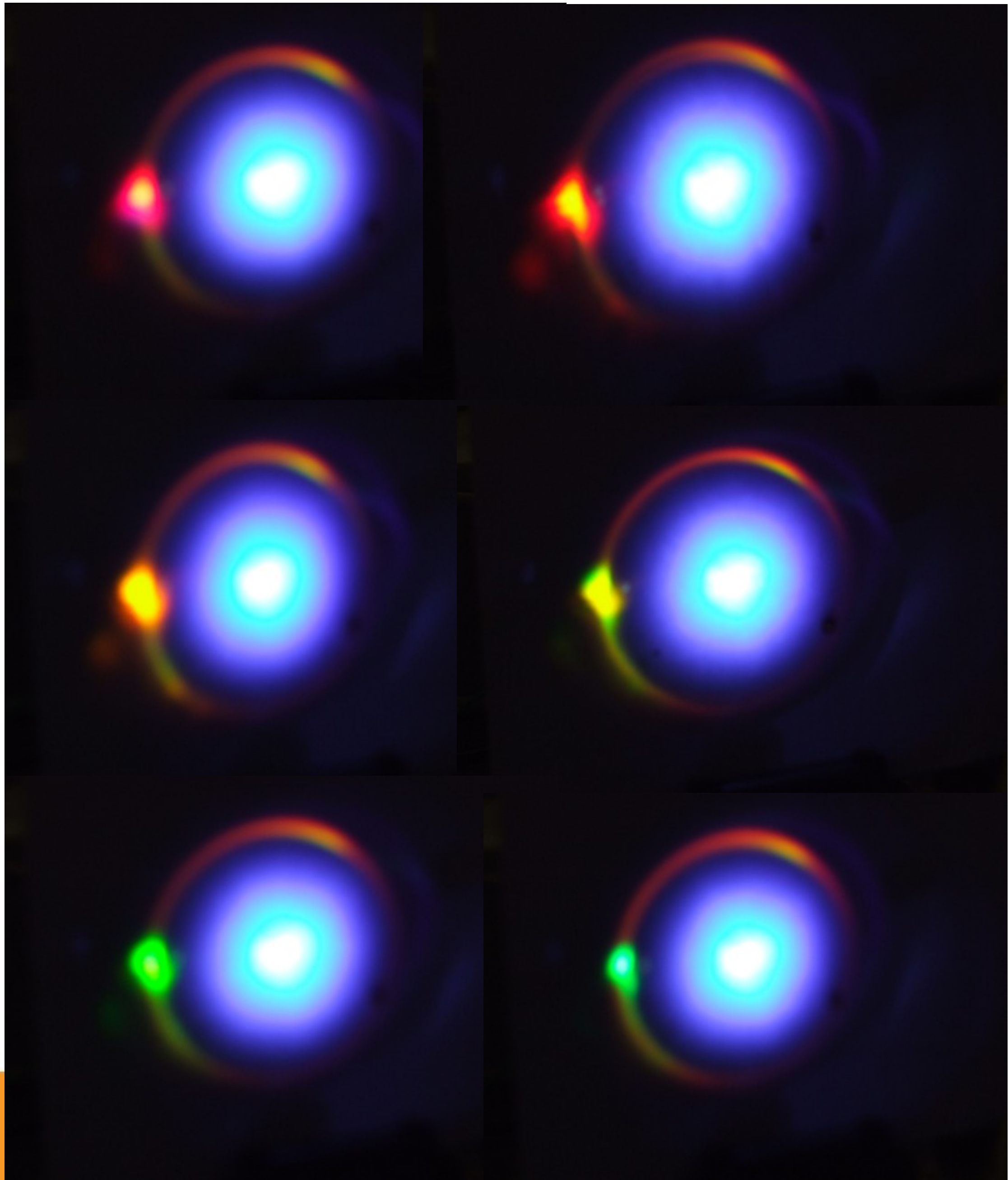
Parametric scattering



The hottest news from the lab







Conclusion

- We have determined the maximum bandwidth for the collinear and non-collinear SHG in the most common nonlinear crystals (BBO, LBO, KDP)
- Calculated phase matching angles of crystals are in a very good agreement with the experiment
- We are able to convert bandwidth of 150 nm via parametric amplification

Acknowledgements

Petr Hříbek

Thank you for your attention

EVROPSKÁ UNIE

MINISTERSTVO ŠKOLSTVÍ MLÁDEŽE A TĚLOVÝCHOVY

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