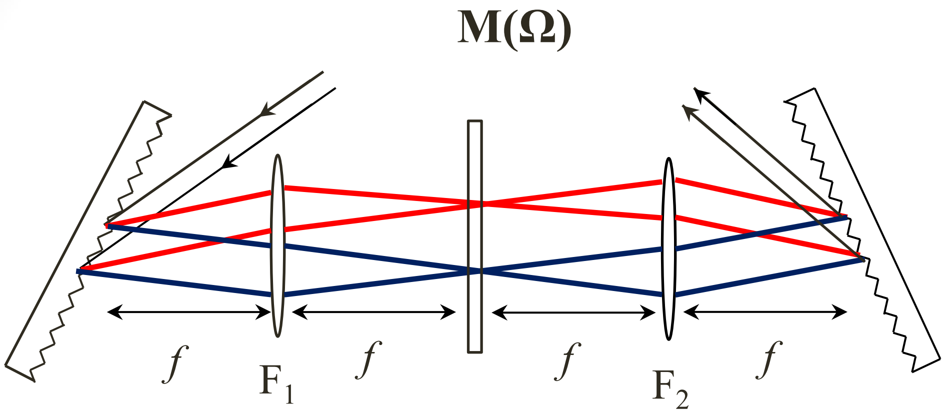
Formation of cylindrical and 3D quasi-ellipsoidal beams for laser driver

Outline

- Basic idea of pulse shaper
- Mathematical model for formation of cylindrical beams
- Experimental set-up
- Experimental results: formation beams with cylindrical and 3D quasi-ellipsoidal intensity distribution
- Conclusion

Basic idea of pulse shaper



Spectrum control:

$$S_{req}(\Omega) = M(\Omega) \cdot S_{in}(\Omega)$$

Fourier transform

$$A_{req}(t)$$

M(Ω) – Spectral mask: in General case - complex function

For linearly chirped pulses: $S(\Omega) = |S_0(\Omega)| \cdot e^{-i\frac{\alpha \cdot \Omega^2}{2}}$

At T>>Tf $|A(t)|^2 \propto |S(\Omega)|^2 \quad \Omega \propto t$

Control at frequency domain linearly corresponds to control at time

Disadvantages:

- No axial-symmetry at the profiled beams
- Strong astigmatism from cylindrical telescope

Mathematical model for formation of cylindrical beams

Gaussian spectral intensity distribution:

$$S(\Omega) = S_0 \cdot e^{-2\ln(2)\cdot\frac{\Omega^2}{\Delta\Omega^2} - i\frac{\alpha\cdot\Omega^2}{2}} \Rightarrow A(t) = \int_{-\infty}^{\infty} S(\Omega)\cdot e^{i\cdot\Omega\cdot t} d\Omega = \frac{\sqrt{2\pi}\cdot\Delta\Omega\cdot S_0}{\sqrt{4\cdot\ln(2) + i\cdot\alpha\cdot\Delta\Omega^2}} \cdot e^{-2\ln(2)\frac{t^2}{T^2} + i\frac{\alpha_t\cdot t^2}{2}}$$

$$T = T_F\sqrt{1 + \frac{16\cdot\ln(2)^2\cdot\alpha^2}{T_F^4}}, \quad \alpha_t = \frac{\alpha\cdot\Delta\Omega^2}{T_F^2 + \alpha^2\cdot\Delta\Omega^2}$$

Spectral mask to produce rectangular spectral intensity: $|S_r(\Omega)|^2 = M(\Omega)\cdot|S(\Omega)|^2$

$$M(\Omega) = \begin{cases} \exp\left(4\ln(2)\cdot\left(\frac{\Omega^2 - \Lambda^2}{\Delta\Omega^2}\right)\right) & |\Omega| < \Lambda \\ 0 & |\Omega| > \Lambda \end{cases}$$

Energy efficiency:

$$\eta = \sqrt{\frac{16\ln(2)}{\pi}} \cdot \frac{\Lambda}{\Delta\Omega} \cdot e^{-4\ln(2)\frac{\Lambda^2}{\Delta\Omega^2}}$$

$$\eta_{max} = \sqrt{\frac{2}{\pi e}} \sim 0.48$$

$$\Lambda_{max} = \frac{\Delta\Omega}{\sqrt{8\ln(2)}}$$

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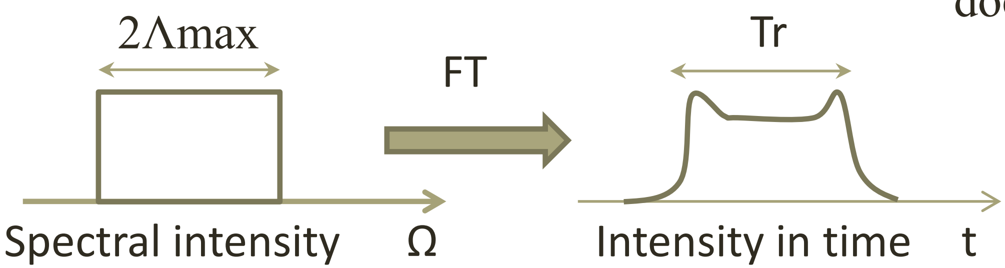
Optimal pulse chirping

How to find optimal α and T?

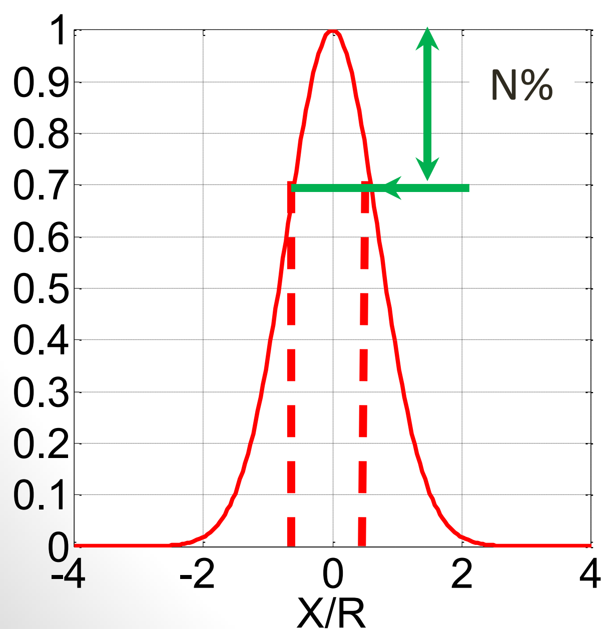


The amplitude mask doesn’t know about spectral phase

$$2 \cdot \Lambda_{max} = \alpha_t \cdot T_r$$

$$T \approx \sqrt{2\ln(2)}T_r \approx 1.17 \cdot T_r$$

Optimal spatial cutting



For cutting Gaussian beams by diaphragm N% intensity deviation from beam center to edge corresponds to N% energy transmission

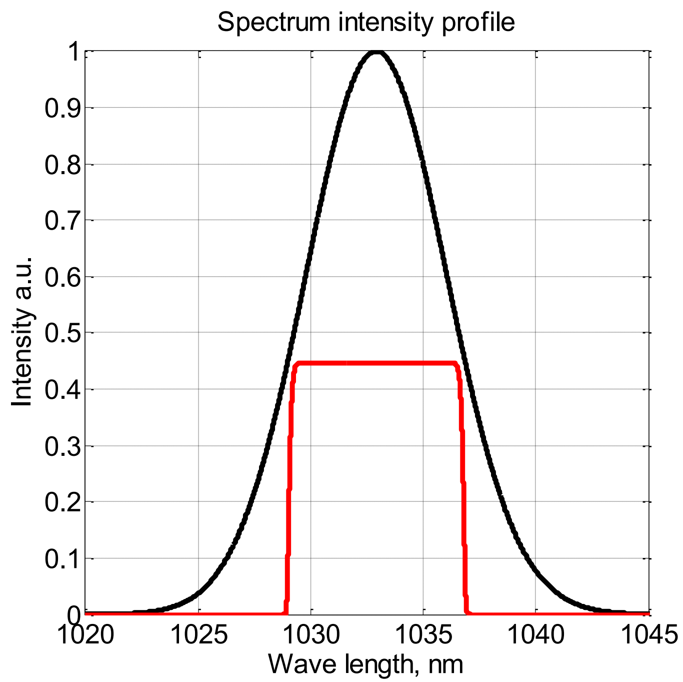
Efficiency can be increased by implementation of “soft“ diaphragm [1].

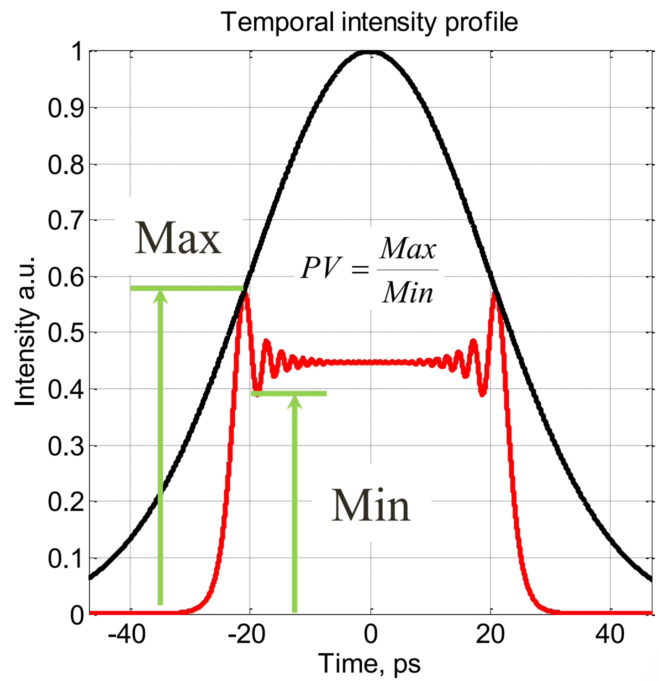
[1] A. K. Potemkin, et. all., "Compact neodymium phosphate glass laser emitting 100-J, 100-GW pulses for pumping a parametric amplifier of chirped pulses", QUANTUM ELECTRON, 2005, 35 (4), 302–310

Soft-spectral mask: pulse front and PV parameter

$$S(\Omega) = S_0 \cdot e^{-2\ln(2)\cdot\frac{\Omega^2}{\Delta\Omega^2} - i\frac{\alpha\cdot\Omega^2}{2}} \qquad M_G(\Omega) = \exp\left(-\left(\frac{\Omega}{\Lambda}\right)^{2N}\right)\cdot\begin{cases}\exp\left(2\ln(2)\,\frac{\Omega^2-\Lambda^2}{\Delta\Omega^2}\right), & |\Omega| < \Lambda\\ 1, & |\Omega| > \Lambda\end{cases}$$

$$S_r(\Omega) = M_G(\Omega)\cdot S(\Omega)$$

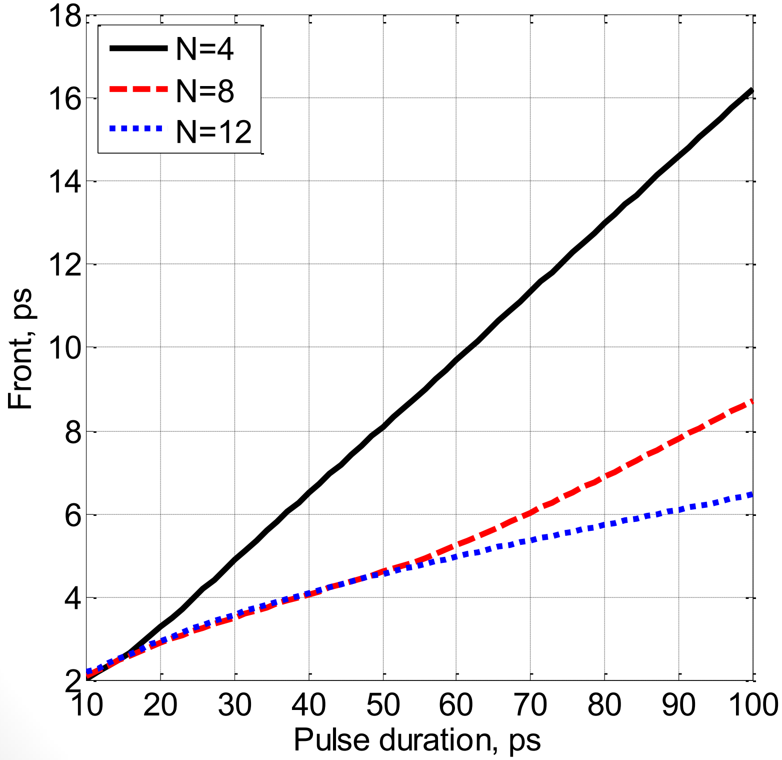


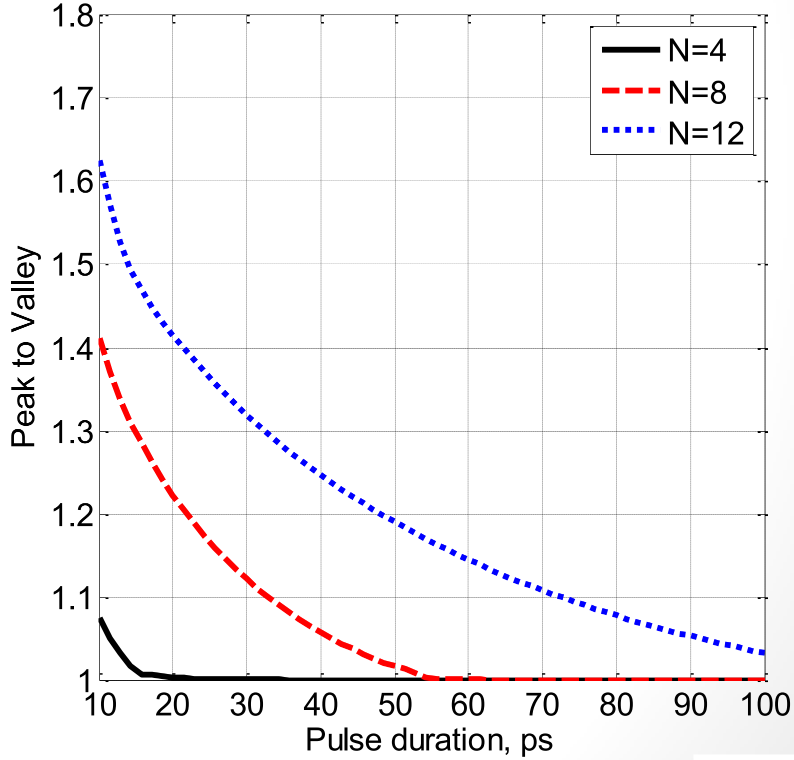


τ_F – Pulse front duration from 0.1*Max till 0.9*Max

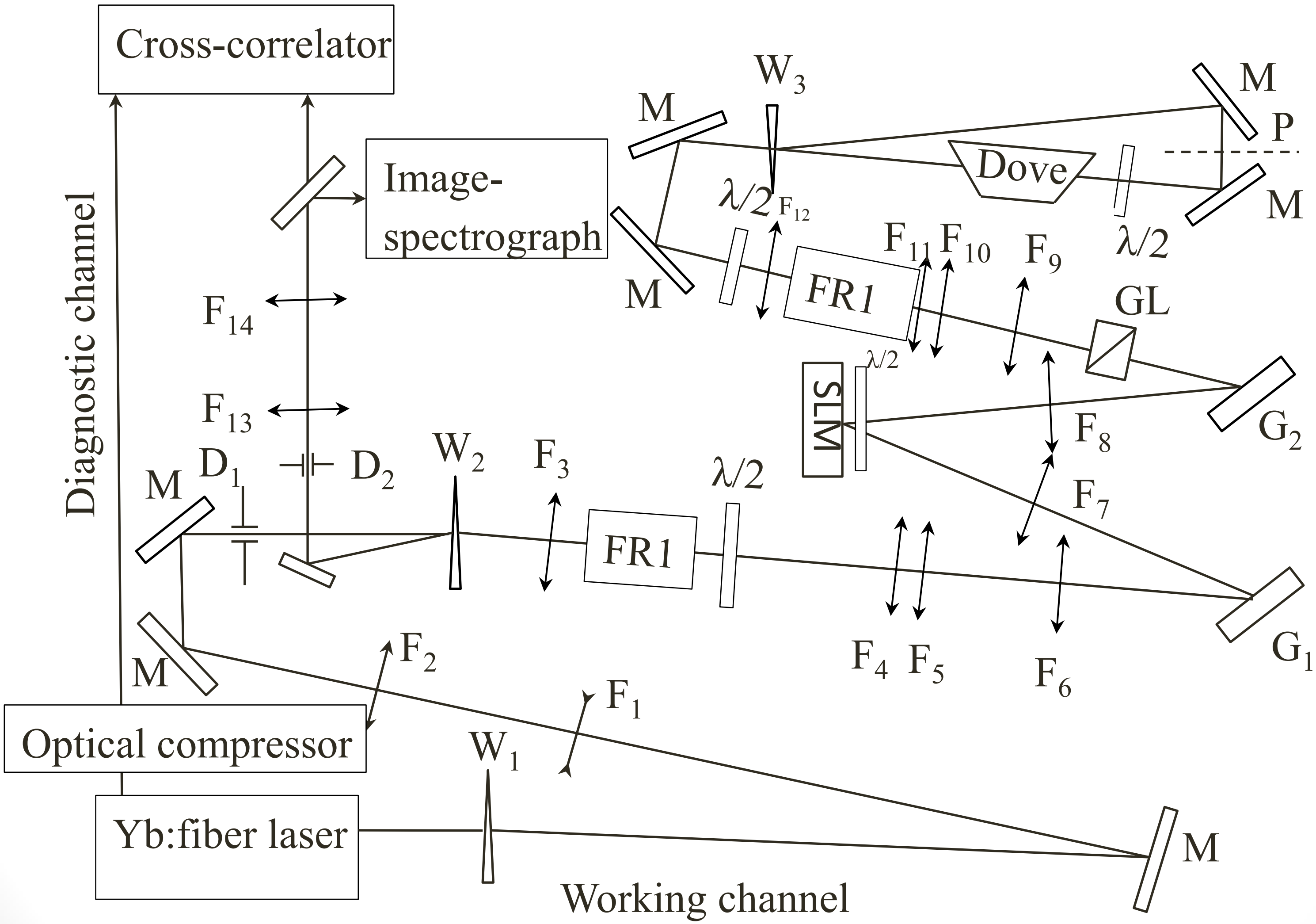
Soft-spectral mask: pulse front and PV parameter

$$M_G(\Omega) = \exp\left(-\left(\frac{\Omega}{\Lambda}\right)^{2N}\right)\cdot \begin{cases} \exp\left(2\ln(2)\frac{\Omega^2-\Lambda^2}{\Delta\Omega^2}\right), & |\Omega|<\Lambda \\ 1, & |\Omega|>\Lambda \end{cases}$$





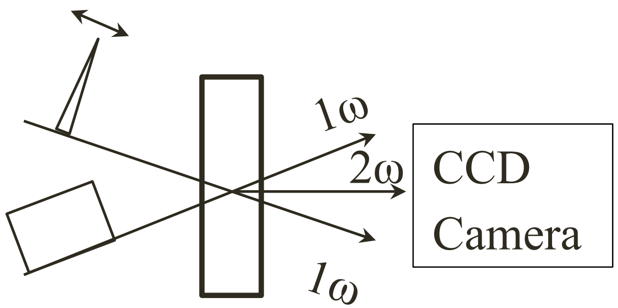
Experimental set up



Output energy: 5.7nJ, pulse duration (FWHM): 41 ps, spectral bandwidth 7.3nm

Used methods for beam diagnostics

Cross-correlator

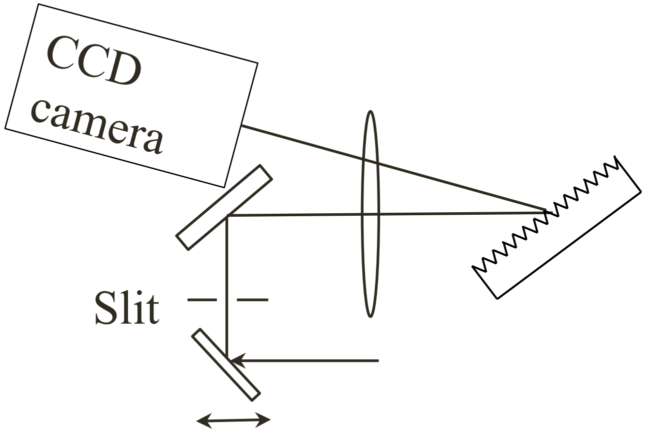


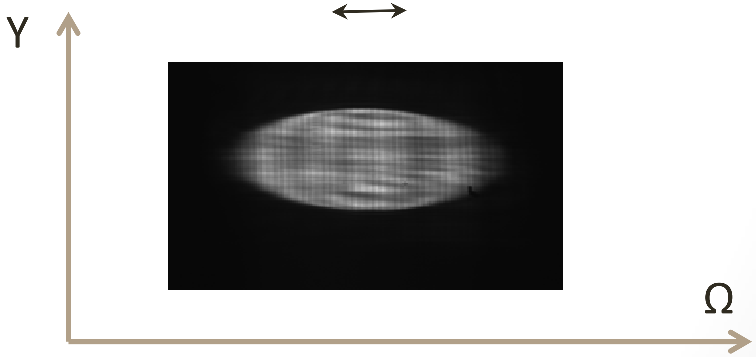
$$W_3(\tau) \sim \int_{-\infty}^{\infty} I_1(t-\tau)\cdot I_2(t)\,dt$$

$$I_2(t) \sim \delta(t) \quad W_3(\tau) \sim I_1(\tau)$$

In this method we collect transversal cross-sections along beam

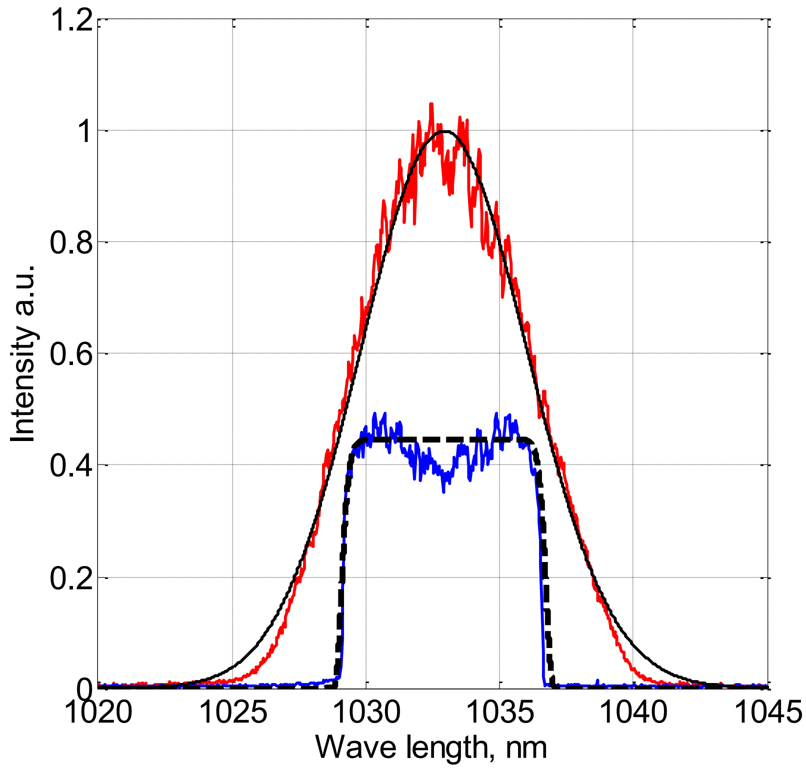
Image-spectrograph

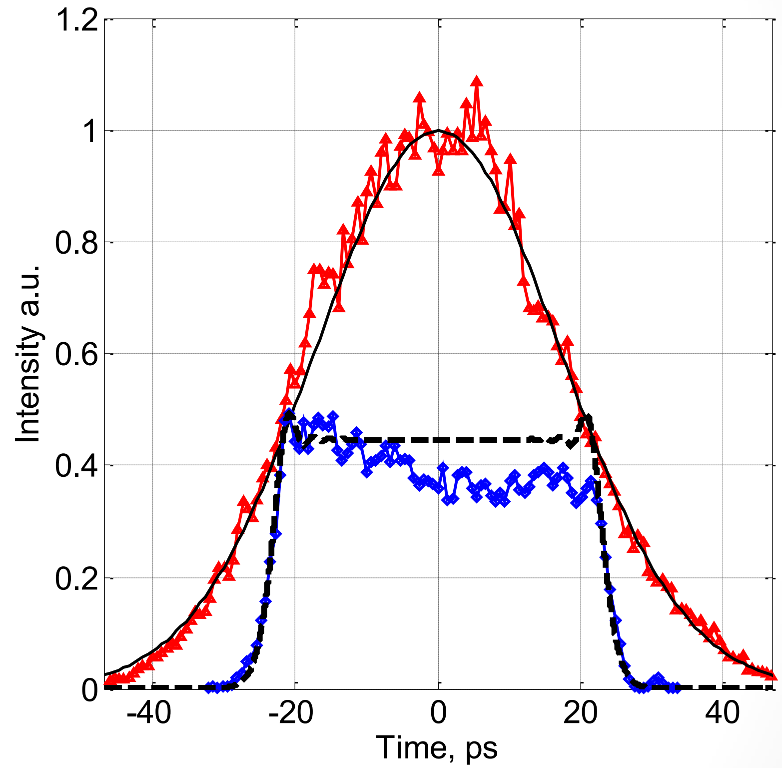




In this method we measure slice YΩ at different positions beam on the slit. It allows obtain 3D spectral intensity distribution

Quasi-cylindrical beams: spectral and temporal intensity distribution

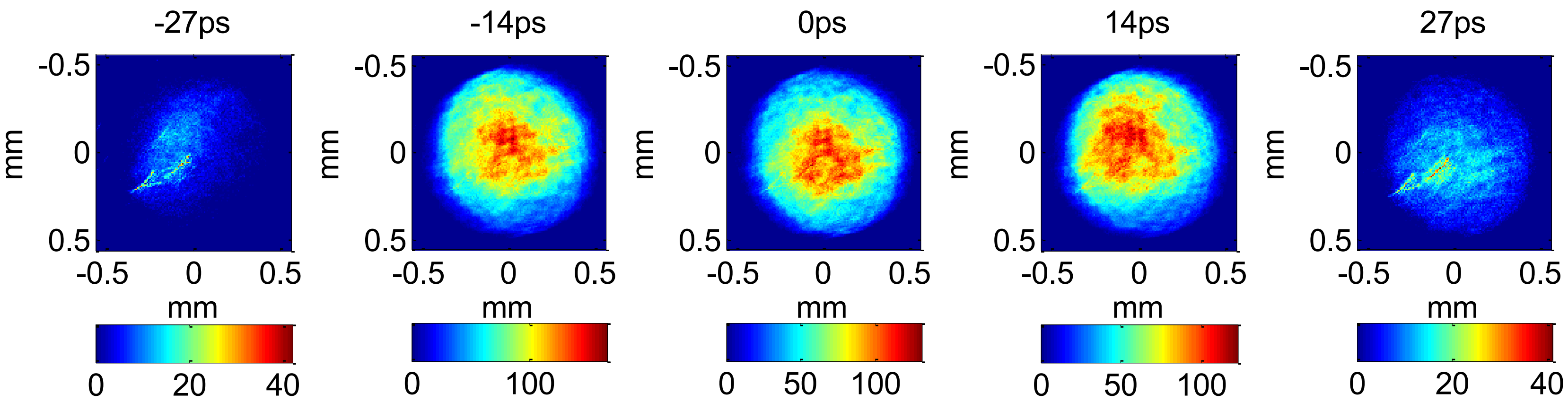


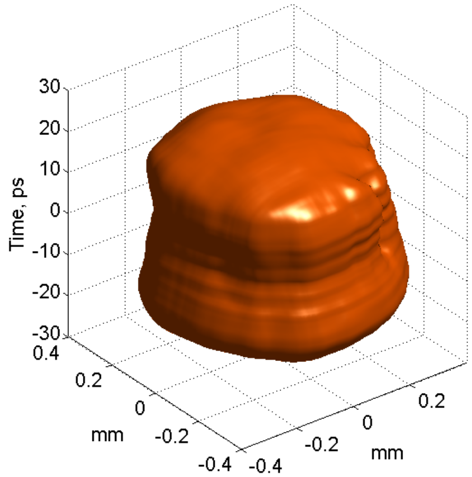


Pulse fronts: $\tau_F = 4ps$ At rectangular pulse duration 41 ps

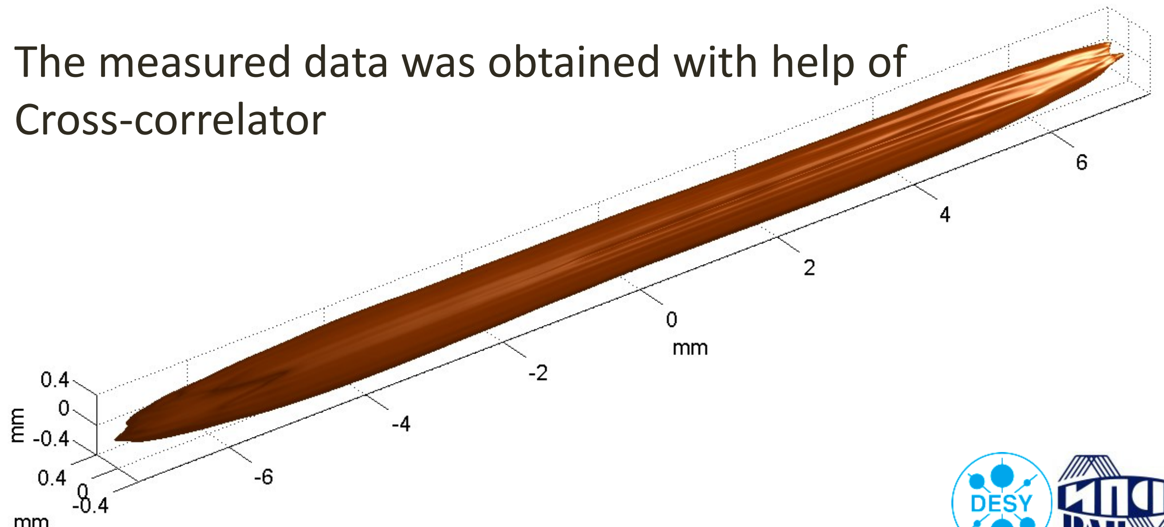
Quasi-cylindrical beams: 3D intensity distribution

Transversal intensity distribution

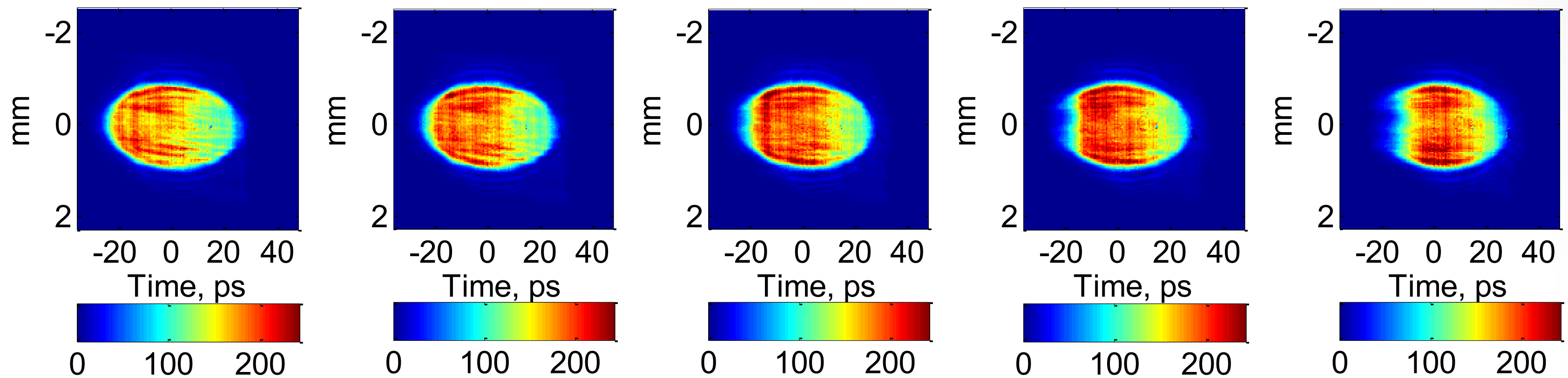


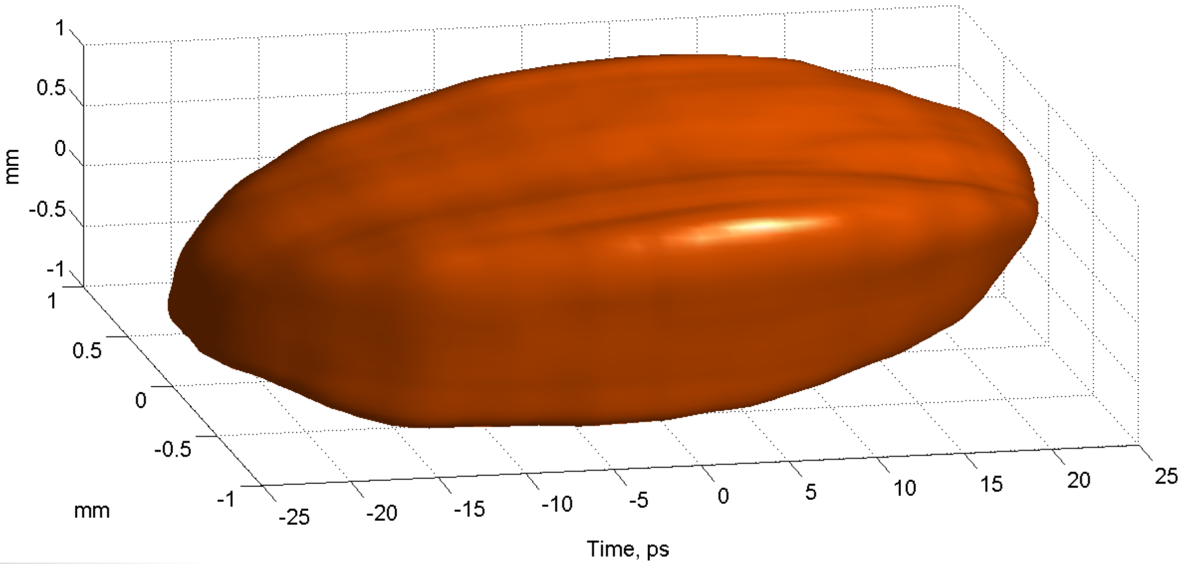


The measured data was obtained with help of Cross-correlator

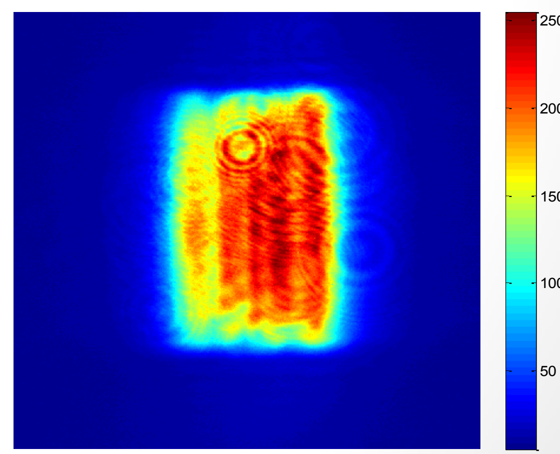


3D quasi-ellipsoidal beams





Near Field



Conclusion

- The mathematical analyze of implementation amplitude mask in pulse shaper has been done
- The pulse shaper scheme was reproduced in IAP RAS with SLM matrix from Hamamatsu
- Cross-correlator and image spectrometer was implemented for beam parameter measurement
- Cylindrical and quasi-ellipsoidal beams were obtained in experiments

Thank you for your attention!