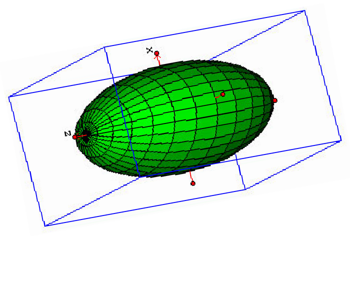
3D Ellipsoidal Shaped UV Laser Pulses for XFEL Photoinjector



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Motivation

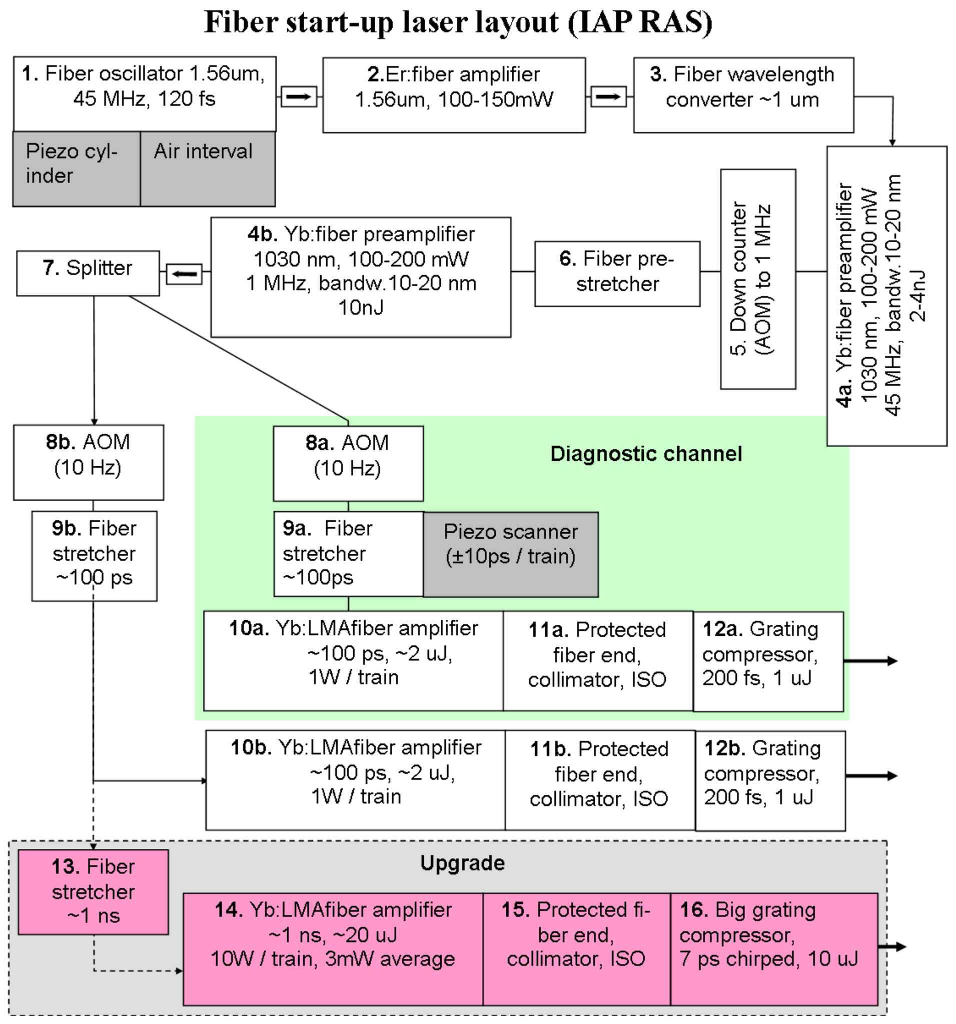
The European X-ray Free Electron Laser (**XFEL**) will allow unprecedented experiments with atomic resolution on femtosecond time scales with ultra-high peak and average brilliance photon beams of transverse spatial coherence. Its construction has already started at DESY in Hamburg. The Photo Injector test facility at **DESY** in Zeuthen (**PITZ**) develops the electron source for the XFEL. The laser driven RF gun has to fulfill very challenging specifications on electron source performance for linac based FELs, namely it should provide electron bunches with high bunch charge (~1 nC) and extremely low transverse emittance (< 1 mm mrad). Recently the attainability of such low emittance has been experimentally proven at PITZ. But even further improvement the electron source quality will strongly extend the scientific reach of the XFEL by allowing e.g. lasing at shorter wavelength, lasing at different wavelengths in parallel, higher repetition rate operation, higher level of transverse coherence allowing lasing from beams of lower energies. The photo cathode laser is a key issue to achieve such a performance. The cathode laser pulse shaping is one of the important tools to reduce the transverse normalized emittance of the electron beam from the photo injector. Beam dynamics simulations show that the **3D ellipsoidal shaping (3DESP)** of the cathode laser pulses as suggested in this project should result in lower beam emittance and more linear longitudinal phase space, which makes possible smoother bunch compression.

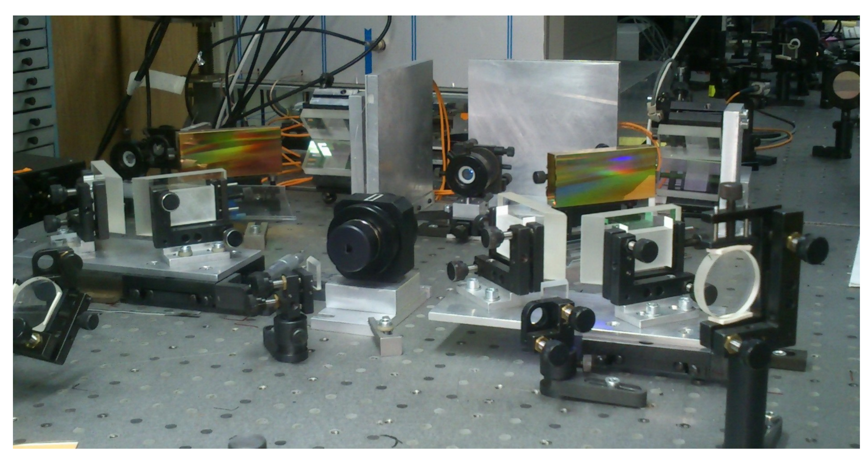
Table 1: Main parameters of the laser system to be developed.

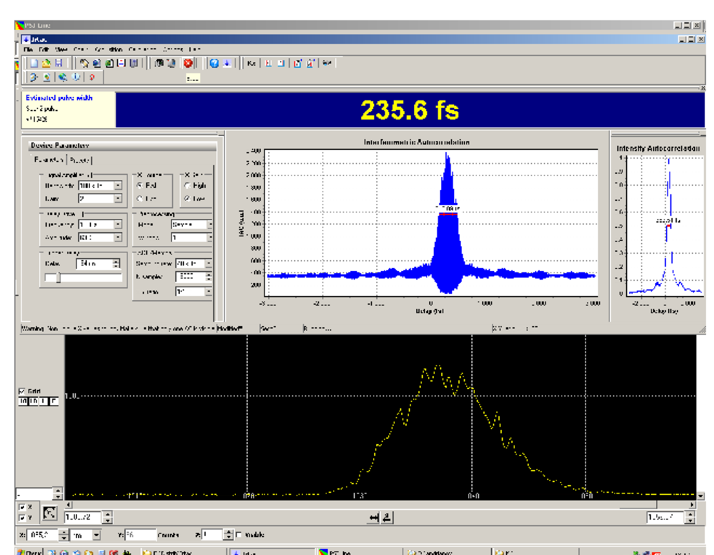
parameter	value	unit	Remark
wavelength	255-270	nm	4th harmonic of Nd
micropulse energy	30	μJ	for 1 nC bunch production from Cs_2Te photo cathodes
pulse train frequency	1	MHz	the final goal is 4.5 MHz
pulse train length	0.3	ms	the final goal is 0.6 ms
Face pulse train rep.rate	10	Hz	1,2,5 Hz as an option
micropulse rms duration	6±2	ps	3D quasi ellipsoidal distribution
transverse rms size	0.5±0.25	mm	

Home-built (IAP RAS) 2-channel 200fs Yb:fiber oscillator and preamplifiers. 1 MHz, 1 Watt per channel

Fiber start-up laser layout (IAP RAS)



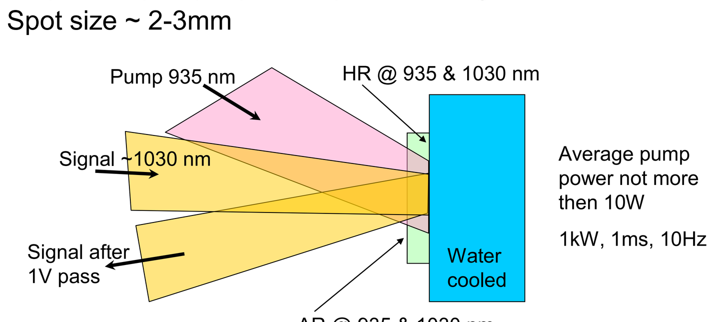


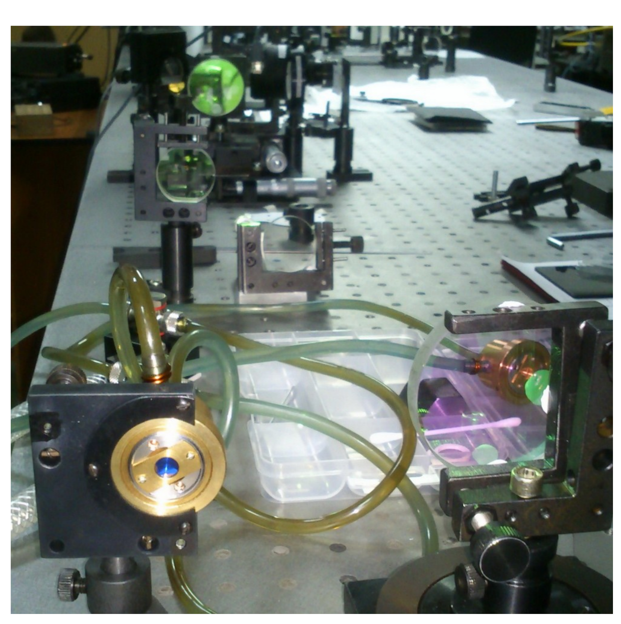


Multi-pass Yb:KGW face-pumped disk amplifier. Diode fiber pump (LaserLine), 935 nm, 2kW, 1ms, 10Hz

3DESP amplification: Solid State Amplifier

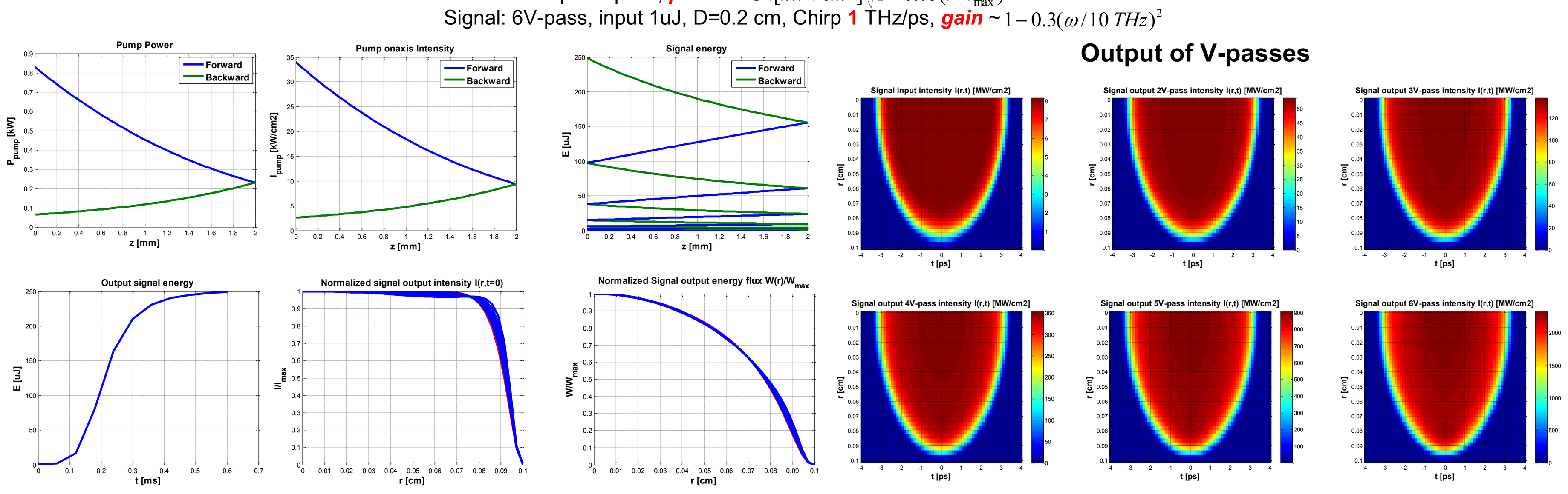
- Active mirror - thin disk (1-2mm)
  5-10% Yb:KYW / KGW
  σNL=2 => L[mm] * Yb[%] = 10
- Face pumped by 935 nm fiber coupled diodes
- 1V pass of pump, up to 6V-passes of signal
- Spot size ~ 2-3mm



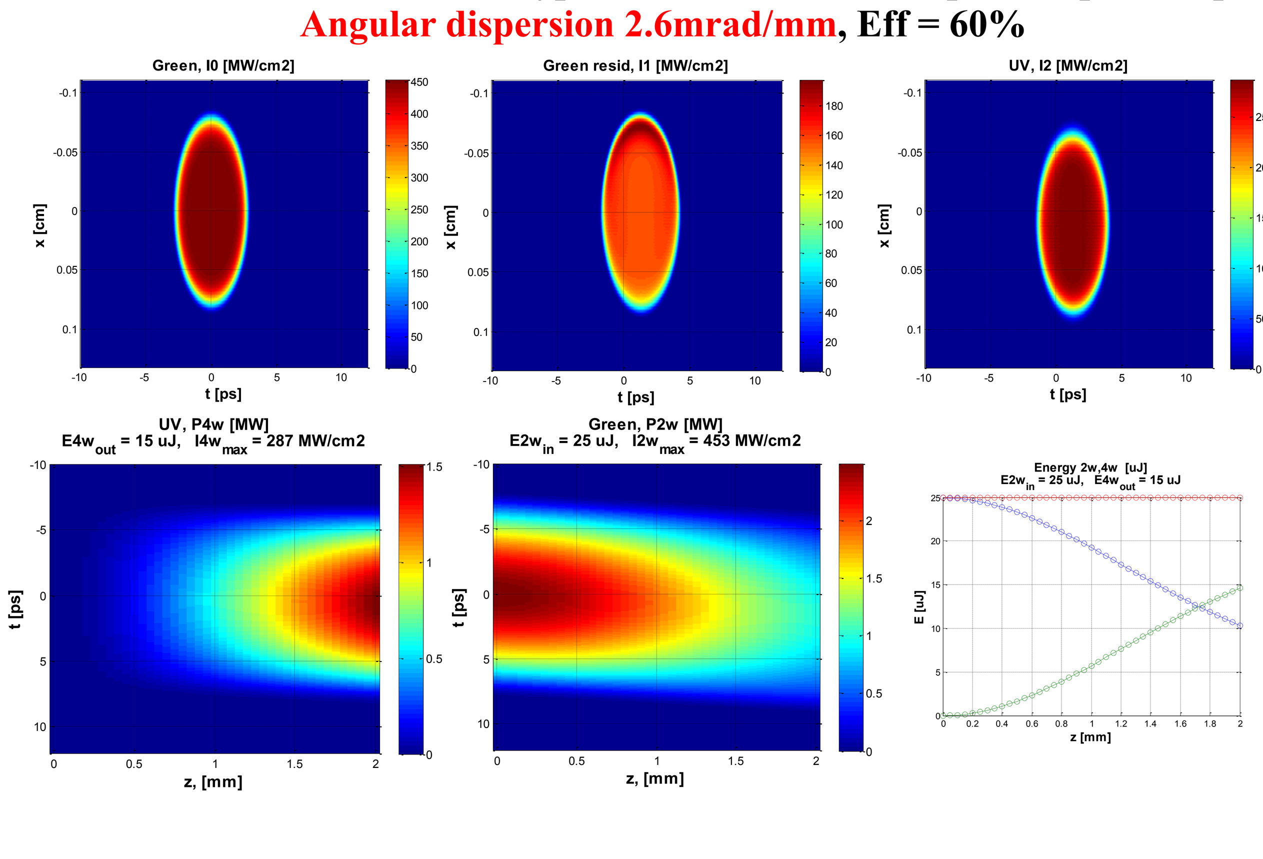


3DESP amplification: Yb:KYW / KGW crystal, E II Nm, z II b II Np
Pump: 1V-pass, ***profile*** $\sim 34[kW/cm^2]\cdot(1-0.75(r/r_{max})^2$
Signal: 6V-pass, input 1uJ, D=0.2 cm, Chirp **1** THz/ps, ***gain*** $\sim 1-0.3(\omega/10\,THz)^2$

Output of V-passes



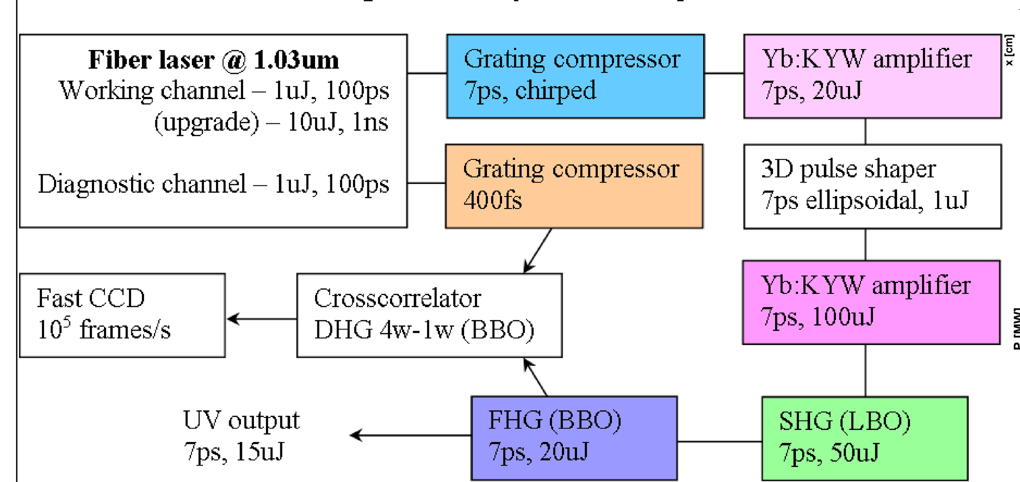
3DESP: FHG, 2mm BBO I-type, 50.2, D=2mm, tau=7ps, Chirp 4THz/ps, Angular dispersion 2.6mrad/mm, Eff = 60%



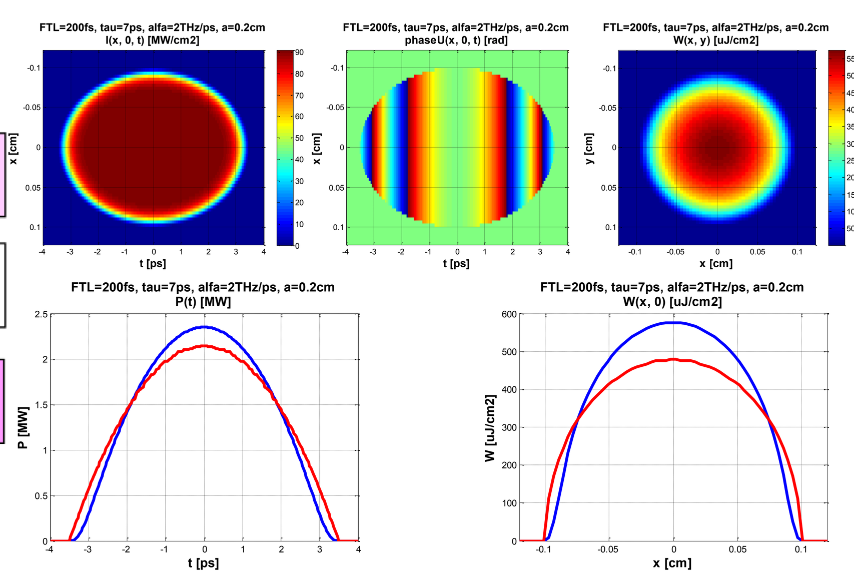
Laser Concept

The proposed laser concept is shown on fig.1. Laser system consists of: fiber oscillator and preamplifier that deliver about 1uJ and chirped 100ps pulses (200fs Fourier transform limit) in both channels (working and diagnostic); grating compressors; solid state amplifiers based on Yb:KYW water cooled disks; 3D pulse shaper based on zero-order compressor with two SLM (Spatial Light Modulators); harmonic stage based on LBO crystal as second harmonic generator and BBO as fourth harmonic generator. The major concern is to detect the shape of the resulted radiation, cross-correlator based on difference frequency generation (4ω-1ω) is suggested to use for this purpose. The signal on difference frequency (third harmonic) is the result of cross-correlation between elliptically shaped 7ps UV pulse and compressed 400fs diagnostic pulse on fundamental wavelength (1.03um). The scanning delay line is set up in the fiber diagnostic channel and will be described below in details. Another key element of 3D diagnostics is a fast CCD camera that is capable to record a short movie with a frame rate from 50000 fps up to 250000 fps. The creation of such camera is a challenge so there are only a few manufactures, but such cameras are exist on the market (eg. see www.photron.com FastCam SA1.1).

Fig 1. Laser system concept



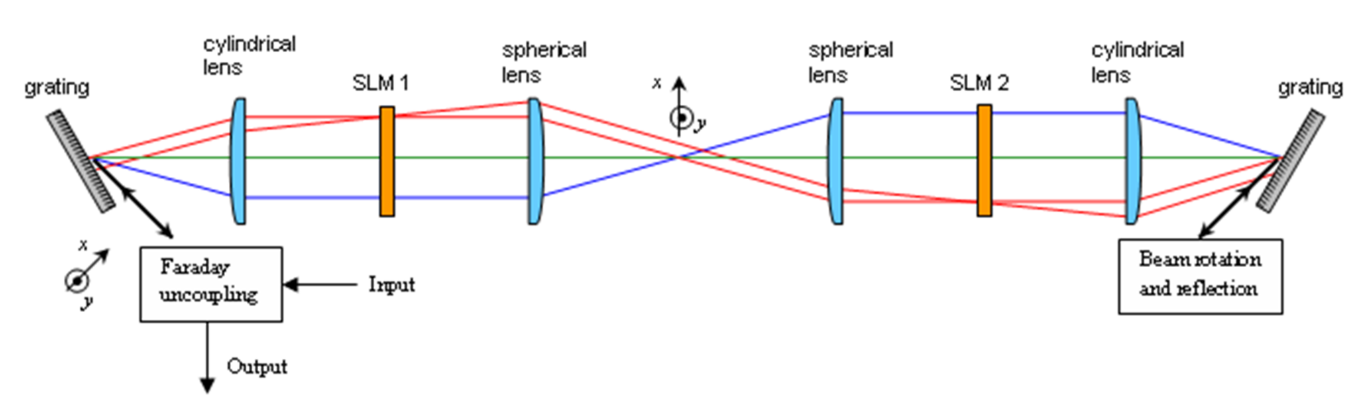
3D Ellipsoidal Shaped Pulse (chirped): Overview



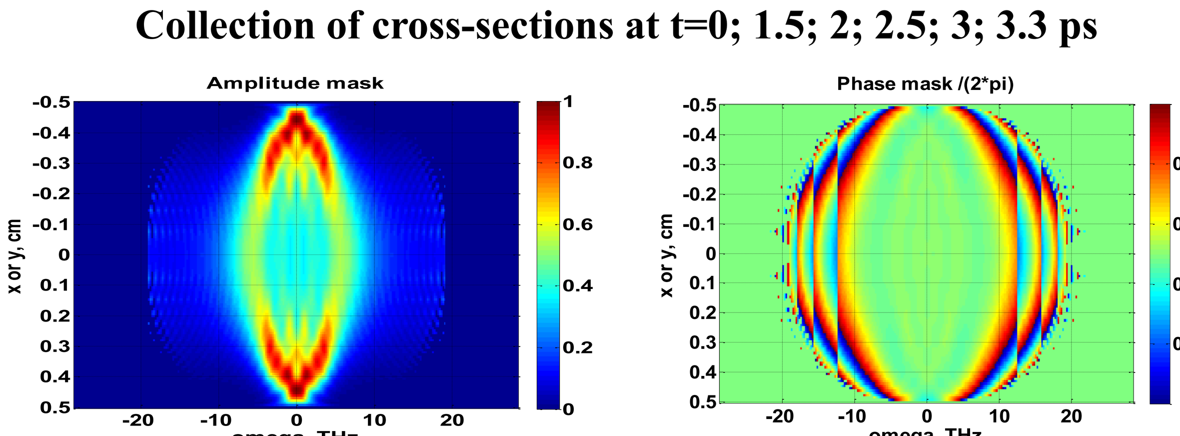
3D Pulse Shaper

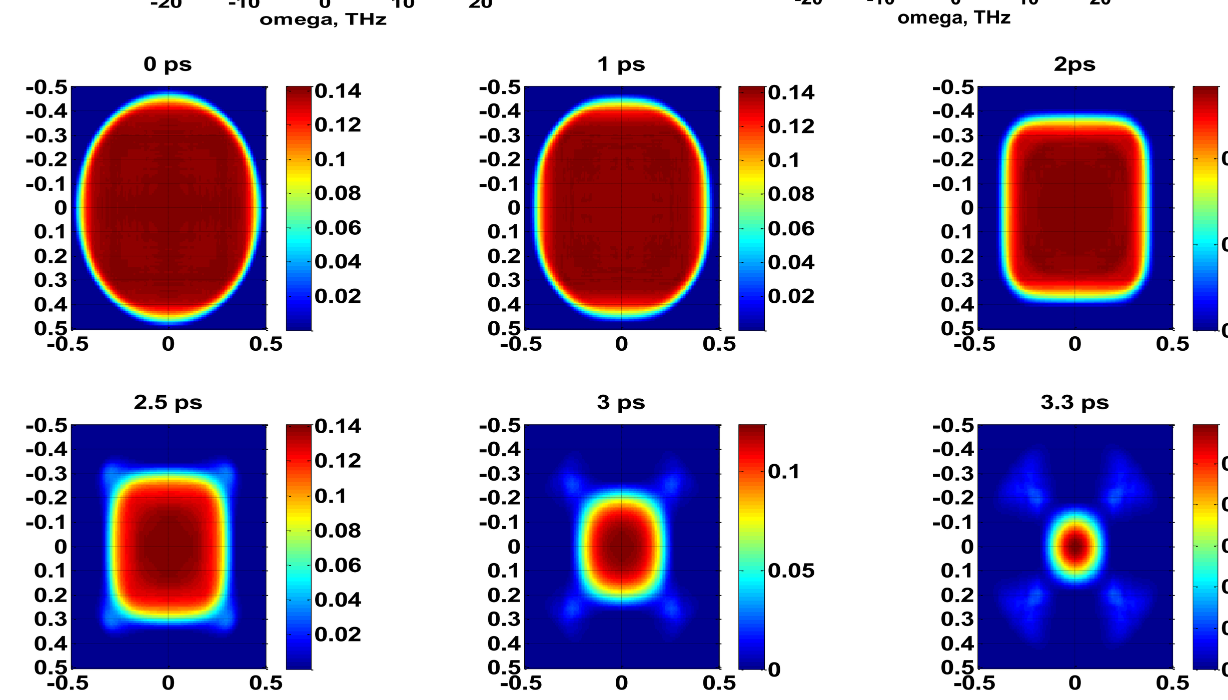
The 3D pulse shaper layout is shown on fig. 2 (top view). It consists of zero-order compressor with two SLM (Spatial Light Modulators) in the focal planes of telescopes. Each telescope is formed by cylindrical and spherical lens, so there is an image relay from one grating to another in x-direction, and one SLM to another in y-direction. The main idea of the shaper is to use two SLM's: one of them is an amplitude mask and another – phase mask. When the beam propagates from left to right in the plane of SLM 1 each spectral component of the pulse corresponds in the geometrical optical approximation to the vertical (y-direction) line, so in the planes of SLM's we have access to both spatial and spectral coordinates of the beam: y and a wavelength. After one passage through this system the beam should be rotated and reflected back in the same polarization. This can be done with the help of periscope and Faraday element. After two passages through the system the forward and backward beams are separated with another Faraday cell.

Fig.2. 3D pulse shaper layout.



3DESP Shaper: Chirp 2THz/ps, two 2D-Masks Collection of cross-sections at t=0; 1.5; 2; 2.5; 3; 3.3 ps





3D Pulse Diagnostics

The 3D pulse diagnostics is based on the DFG cross-correlator. Working UV pulse is mixed on the nonlinear crystal with diagnostic pulse and difference frequency @ 343nm is generated. This signal is captured by a fast CCD camera. The idea is to record a movie where each frame corresponds to different delays of the diagnostic pulse (see fig.3). The delay of diagnostic pulse is provided by piezo-cylinder inside the diagnostic channel of the fiber part of the laser. Ideally we need a CCD camera that is capable to capture at 1Mfps (fps = frames per second) but unfortunately such camera is not available. It reasonable to relay on 100Kfps camera, so each frame will be filled by approximately ten nearest cross-correlation traces. Finally it is possible to obtain about 30 frames that correspond to the same number of 3D beam cross-sections. This info is sufficient to fully reconstruct 3D structure of the pulse. The major challenge is the fast CCD camera, such cameras are exist on the market (eg. see www.photron.com FastCam SA1.1), we are now working towards the reliable and cheapest solution. Recently the cross-correlator was buit at IAP RAS, the cross-correlation between 200fs pulse from the diagnostic fiber channel and chirped 7ps pulse from main channel is shown on the figure (yellow curve), corresponded linear voltage on the piezo-cylinder is shown by the blue curve.

Fig. 3. 3D pulse diagnostic