The last POLARIS amplifier A5

The 5th POLARIS amplifier has the goal to reach laser output energies of up to 100 J. For this reason the output energy of the 4th POLARIS amplifier A4 (10 J) has to be increased at least by factor of 10. A5 occupies a volume of 5x2.5x2.5 m^3 and comprises - in addition to optical components of the beamline - approximately 500 electronic devices. All components must work together as one big system. The pump system is currently equipped with 120 laser diode stacks with an optical power of 2.5 kW each as a pump source. We use Yb^{3+}-doped CaF_2-crystals or Yb^{3+}-doped FP-glass with 70 mm diameter and 10 or 30 mm thickness as the active laser medium. The work at A5 covers a wide field of activities starting from mechanical installation and maintenance of technical environment to development of computer based control- and supervision system. Of course, the main topic is the setup and the operation of the optical beamline for the 35 mm diameter (FWHM) laser beam.

Further improvements will directed towards increasing the optical damage threshold of the active laser medium and the installation of a cryogenically cooled laser head. The limitation by damage threshold is currently the bottle neck of A5. The cooling with liquid nitrogen will help to increase the thermal conductivity of the CaF_2 crystal and allow for a higher repetition rate. Furthermore, the transition from a quasi 3- to a real 4-level laser scheme takes place and will allows for more efficient usage of the pump energy.

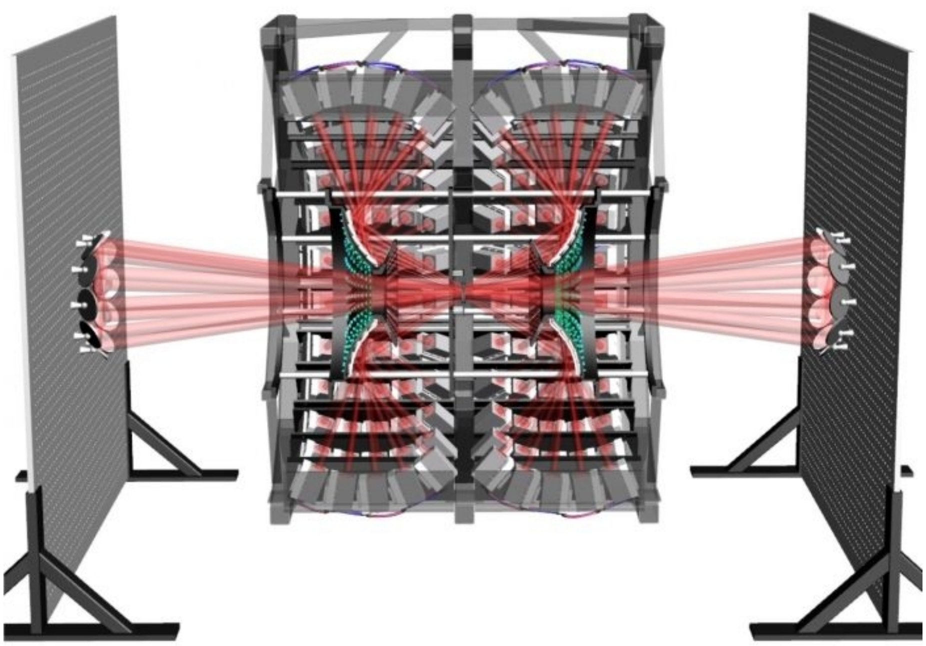


Fig. 1: Artistic view with a cross section of the pump engine in the middle and two vertical optical tables on the sides

Improvement of the pulse contrast by means of optical parametric amplification (OPA)

Besides using the POLARIS laser for high-intensity laser experiments, our group is always striving to improve the laser performance itself. A big challenge in this field is the improvement of the pulse contrast, i.e. the temporal purity of the pulse. One wants to avoid pre- and post-pulses and suppress the background of amplified spontaneous emission (ASE) to intensities as low as possible. To achieve that, we follow multiple approaches. One of them is taking advantage of optical parametric amplification (OPA).

We are designing and realizing a diode-pumped amplifier chain which is working parallel to the POLARIS laser. The requirements for the amplifiers regarding pulse contrast and spectral bandwidth are relatively low. The amplified pulse at a central wavelength of 1030 nm is frequency-doubled to 515 nm. This green light is then used to pump a nonlinear crystal. The crystal is the centerpiece of the amplifier for the POLARIS pulses and it is expected to have a very low ASE-level and a very good pulse contrast because of the nonlinear amplification properties.

Besides the tests regarding the OPA-process for contrast improvement we are also testing new laser materials and amplifier layouts in the context of such approaches. In this particular case we are testing ytterbium-doped lutetium aluminum garnet as the laser material in a regenerative amplifier and a novel relay-imaging amplifier design consisting of cylindrical optics to compensate for astigmatism (see fig. 2).>

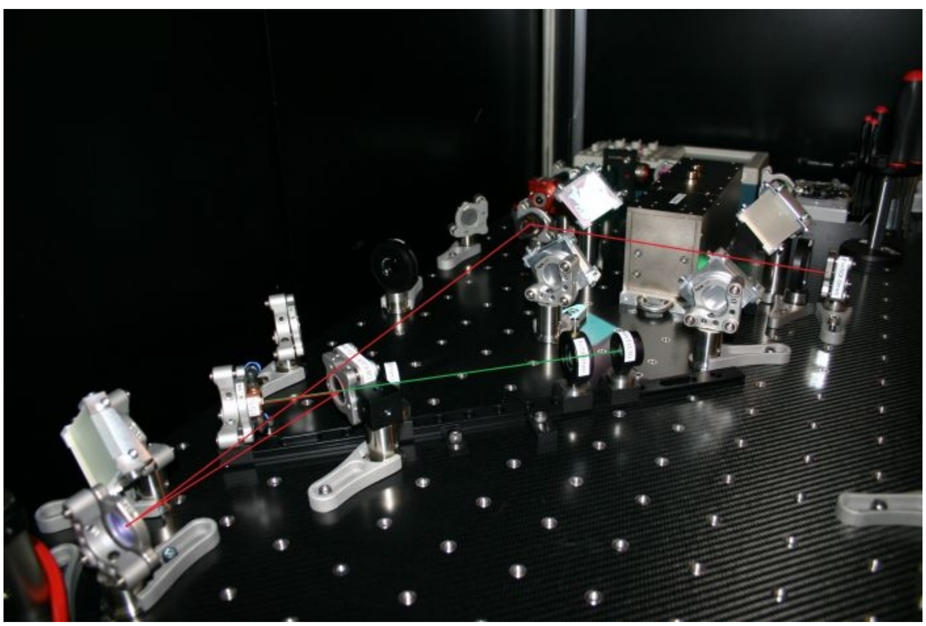


Fig. 1: View on the regenerative amplifier: Green is the pump radiation, red is the pass of the pulse to be amplified. The other optics are required for the relay imaging.

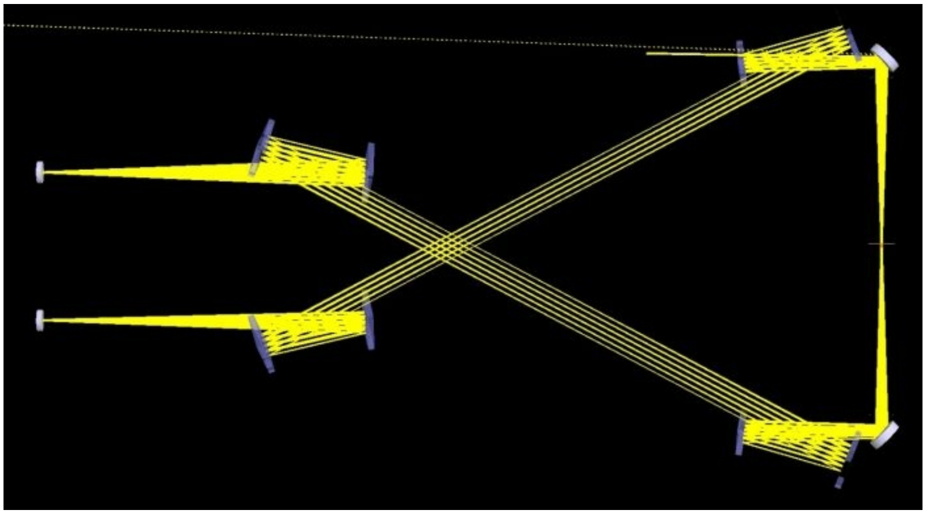


Fig. 2: Top view of the optical path in the relay-imaging with 10 amplification passes

A Double-CPA System - an alternative front-end for contrast enhancement

When performing experiments with high-power, ultrashort laser pulses, the intensity in the focal spot exceeds 10^{20} W/cm^2. Thus the requirements for the temporal quality of those pulses are demanding. Especially the temporal intensity contrast, defined as the ratio between the main pulse intensity and the intensity of the optical radiation preceding or succeeding the main pulse, plays a major role for conducting successful experiments, e.g. towards particle acceleration.

For reaching a high temporal intensity contrast, one has to develop methods to avoid the generation of secondary radiation (ASE, amplified spontaneous emission) and secondary pulses (pre- and post-pulses) or to suppress them, in particular in the first regenerative amplifiers ("front-end").

In the context of laser development at the POLARIS system we are permanently developing and investigating principles to enhance the temporal contrast of the laser-pulse (e.g.: double-CPA, nonlinear filtering such as crossed-polarized wave generation, XPW…)

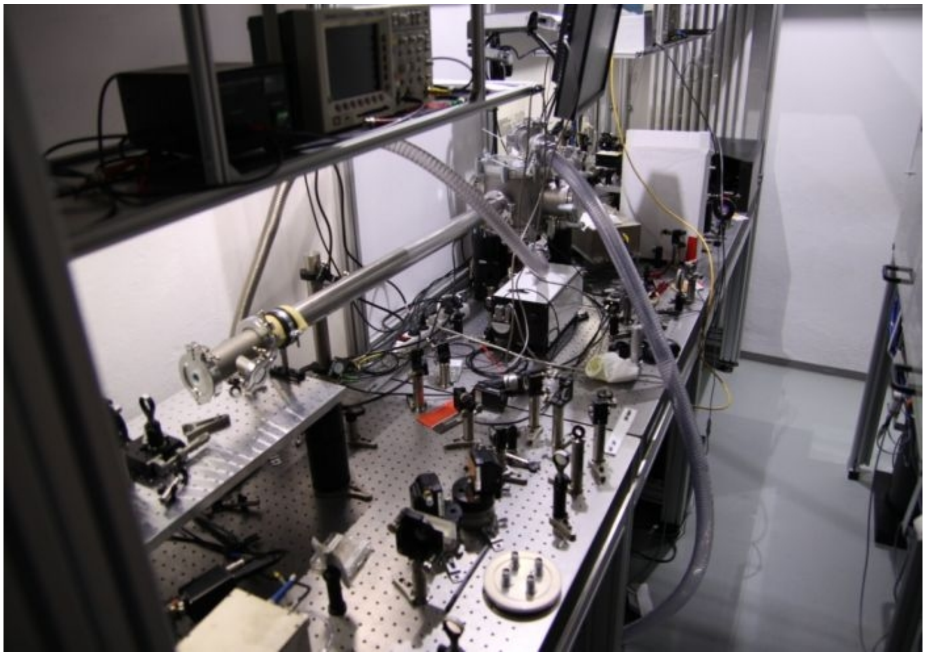
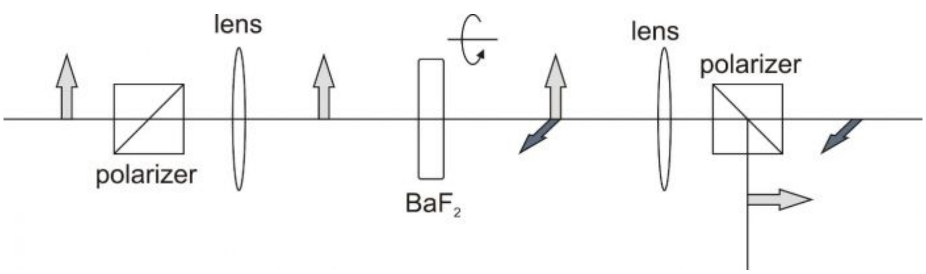


Fig.1: Alternative front end for temporal filtering



Generation of a few-cycle optical probe pulse for the investigation of relativistic laser-plasma interactions

The investigation of relativistic laser-plasma experiments involves a variety of diagnostic methods. Whether using gas targets for electron acceleration or solid targets for ion/proton acceleration or surface high harmonic generation, actively probing the electron density of the generated under-dense plasma using a pump-probe technique can reveal important information about the interaction under study. Furthermore, due to the relativistic motion of structures inside the plasma, a high temporal resolution of the probing technique becomes a critical requirement. Using a multi-Terawatt Ti:sapphire laser system as the pump laser, our research group has developed a few-cycle probe pulse in the VIS-NIR spectral range that can be used to backlight the laser-plasma interaction. This pump-probe configuration allows us to record shadowgraphic images of the laser-plasma interaction with sub-10 fs temporal resolution and can be further modified to perform interferometric or polarimetric measurements.

The creation of few-cycle optical pulses is well-established and has been implemented on femtosecond Ti:sapphire laser systems for quite some time. These pulses can be created via spectral broadening via self-phase modulation (SPM) in a gas-filled hollow-core fiber (HCF) followed by temporal compression by chirped mirrors (CMs). Depending on the filling-gas and the incident intensity, a spectrum spanning several hundred nm is achievable. The created spectrum is modulated due to interference effects; however, the technique is capable of supporting few-cycle pulse durations.

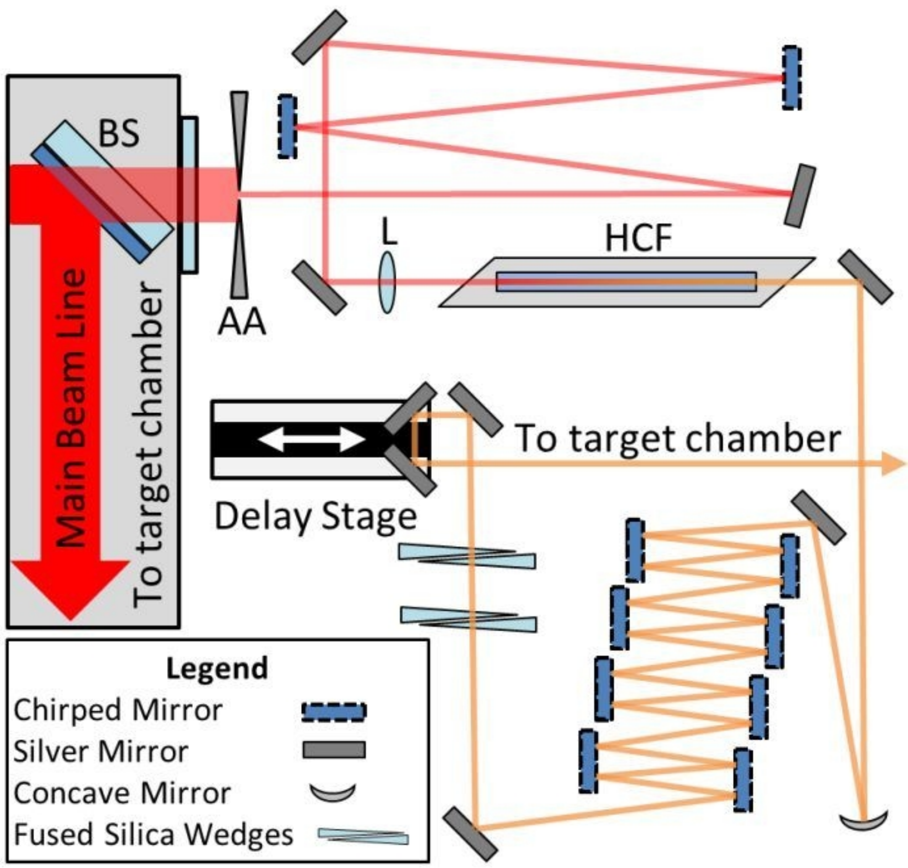


Fig. 1: Few-cycle probe diagram

Figure 1. shows a diagram of the probe's setup. 1% of the pump-pulse's energy is picked off by a 99:1 beamsp-litter (BS) creating a probe pulse that is synchronized with the pump pulse. After the probe's beam diameter is reduced in size by an apodized-aperture (AA), two CMs temporally compress the probe and a one-meter focal length lens (L) focuses it into a gas-filled HCF. The probe's quadratic dispersion is controlled such that its shortest pulse duration, i.e. highest intensity, is realized at the entrance to the HCF. The resulting SPM broadens the probe's spectrum enough to support a sub-5 fs pulse duration. Upon exiting the HCF, the probe is collimated and a group of 8 CMs once again temporally compresses the probe to have a net negative dispersion. Glass wedges are then used to fine tune the dispersion so that its shortest duration will be achieved in the evacuated target chamber. A delay stage is also used to set the relative timing between the pump and probe pulses in the interaction region.

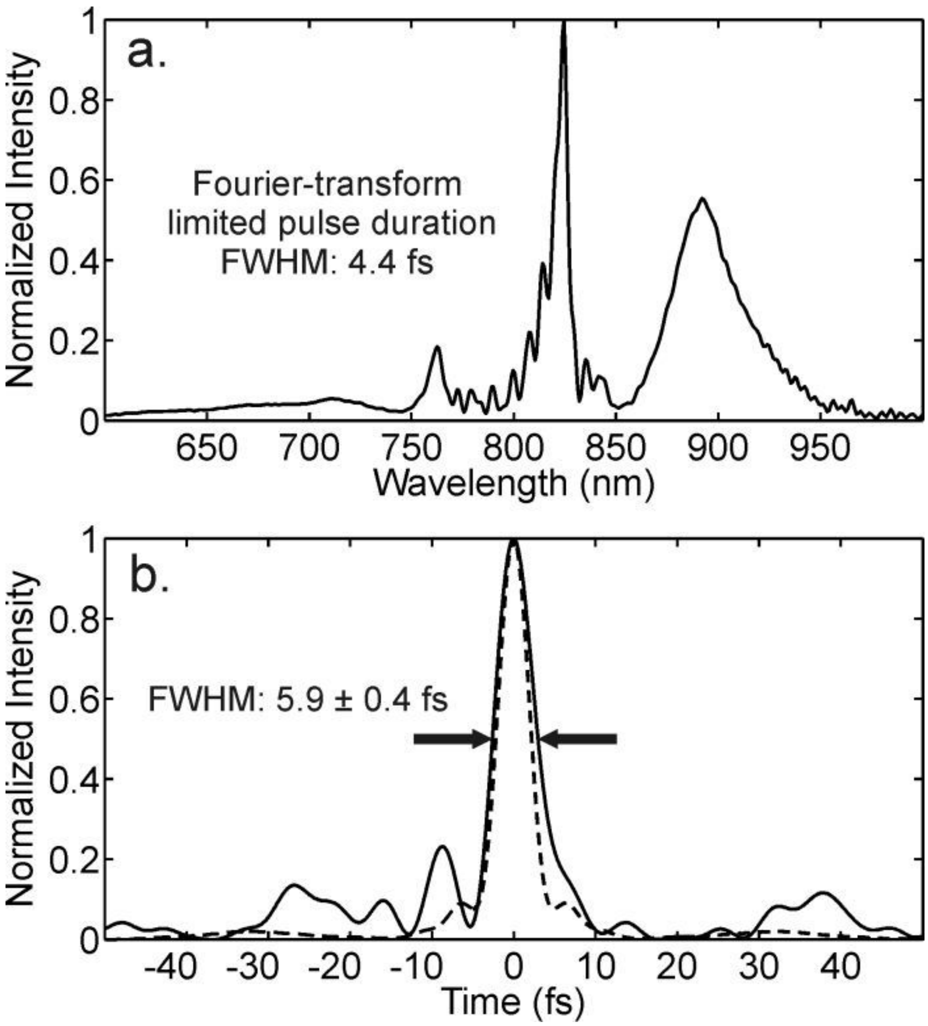


Fig. 2: Spectral and temporal measurements of probe

The probe setup was characterized using argon gas in the HCF. The resulting broadened spectrum supported a Fourier-limited Full Width Half Maximum (FWHM) intensity pulse duration of 4.4 fs. Measured FWHM probe durations fell within 5.9 ± 0.4 fs with a pulse energy of 300 ± 15 µJ exiting the HCF.