PHELIX, a Petawatt High Energy Laser for Heavy-Ion Experiments

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The laser building for PHELIX [1], started with the ground-breaking in December 1999, was finished in August. It was inaugurated as part of the celebration of 30 years of GSI by the German Federal Minister für Bildung und Forschung, E. Buhlman and the Hessian State Minister für Wissenschaft und Kunst, R. Wagner (Fig.1)

Fig. 1.: Inauguration of the laser building August 25th 2000 by the German Bundesminister für Bildung und Forschung, E. Buhlman (with scissors) and the Hessian Staatsminister für Wissenschaft und Kunst, R. Wagner

On the ground floor the building houses the 500 m^2 laser hall for the main amplifier and the laser front-ends and an additional preparation space of 60 m^2. These rooms are equipped as class-10000 clean rooms. A mirror tower, solidly anchored to the 90 cm-thickness foundation plate, will lead the beam up to the beam switchyard on the second floor. Here also the pulsed power bay, the control-room, and a 60 m^2 class-100 clean room for the assembly of laser optics are situated. The building was engineered to allow operation and target delivering of the laser at the typical level of ground vibrations found under operation of the accelerator and the installations in the accelerator halls.
In parallel to the construction, preparations of the laser installations were made. The design parameters of the main amplifier [2][3] were verified by calculations performed at the Lawrence Livermore National Laboratory in Livermore, California, and at the CEA laboratory in Le Barp, near Bordeaux. The conclusion was to foresee 5 amplifier heads within the 2-pass amplifier. This will allow to create pulses with up to 1 Kilojoule in this first part of the amplifier, and to reach values necessary for Petawatt operation with only this section. In the booster amplifier, isolated by a Faraday isolator, 5 more amplifiers are planned to increase the energy level to 5 Kilojoules for 5 ns to 10 ns pulses. The floor plan of the laser installation is shown in Fig. 2.
This makes it possible to send pulses up to the 1-Kilojoule level directly to the experiments, and to inject into the booster amplifier section only for the high-energy option.

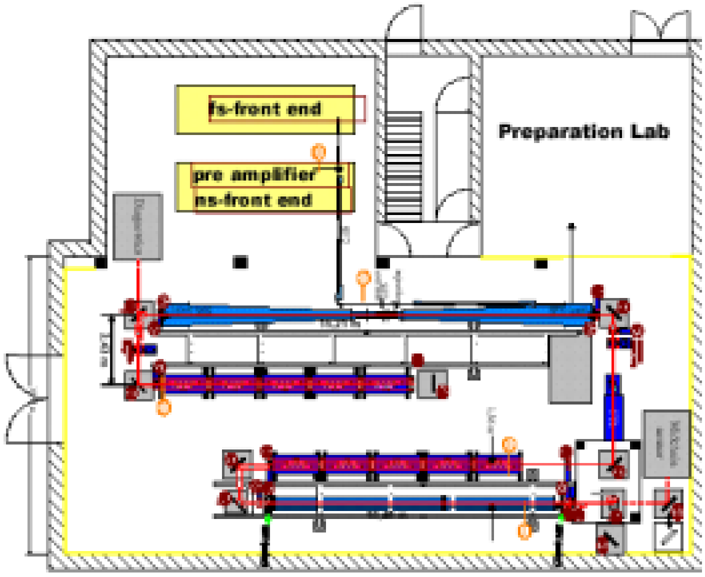

Fig. 2.: Modified lay-out of the PHELIX chain.

Shortly after the laser building became utilizable the fs-front-end components were shipped and installed. This system consists of a commercial femto-second oscillator, pumped by a diode-pumped Nd:YVO_4 laser, and two custom-built regenerative amplifiers. The first parts of the PHELIX nanosecond front-end have been assembled and tested. The ns-frontend basically consists of seven individual parts, the fiber-oscillator, a fiber-based double pass amplifier, an amplitude modulator to tailor the temporal pulse shape, a phase modulator to provide additional bandwidth, a fail safe system to protect the bigger laser components, a ring regenerative amplifier and a beam shaping section to modulate the spatial laser beam profile. Within 2000 the first three parts have been built and tested in close collaboration with the Lawrence Livermore National Laboratory. The PHELIX design is based on a modified prototype which is to be used for the National Ignition Facility and similar to the Z-beamlet laser system at Sandia. Except for the the ring regenerative amplifier and the beam shaping section the PHELIX ns-frontend is based on fiber technology. This provides stable and robust operation without much further alignment and maintenance. The fiber components are housed in 19” racks that can be placed anywhere inside the laser building.

The oscillator module provides a stable, continuous laser beam of 15 mW, single mode, at 1053 nm delivered by a laser diode pumped Y-doped fiber laser. It is injected into a double pass fiber amplifier, which is shown in Fig. 3.

Fig. 3.: The 19" fiber-optics double-pass amplifier of the ns-frontend.

The laser beam is chopped by an acousto-optic modulator into individual pulses of 100 ns length and amplified to several nanojoules (corresponding to a few Watts peak power) with the aid of a laser diode pumped Y-doped fiber and a Bragg grating used as a fiber end-mirror.

These pulses are then sent to the amplitude modulator section. The modulator consists of two fiber based Mach-Zehnder interferometers made of Li-Niobate. If a low voltage electrical signal is applied to one arm of each of the interferometers, it changes the refractive index of the material and therefore causes a modulation of the exiting laser radiation. The electrical input signal is converted into temporal shaping of the laser pulse. The temporal resolution of the modulator is better than 100 picoseconds, mainly limited by the driving electrical circuit.

For most of the future experiments planned for PHELIX, nanosecond temporal resolution is required. Thus, and due to the varying experimental conditions, a highly versatile electrical pulse generator (arbitrary waveform generator, AWG) is used. Individually designed electrical pulses can be generated in the computer control system and will be transformed into PHELIX laser pulses using the AWG. Fig. 4. shows long term stability test results for the system (oscillator, double pass and modulator). An excellent energy stability was found even though the whole system was housed not in a temperature controlled environment like it will be in the PHELIX building. Furthermore the performance of the modulator section was tested as seen in Fig. 5. The electrical input signal from the

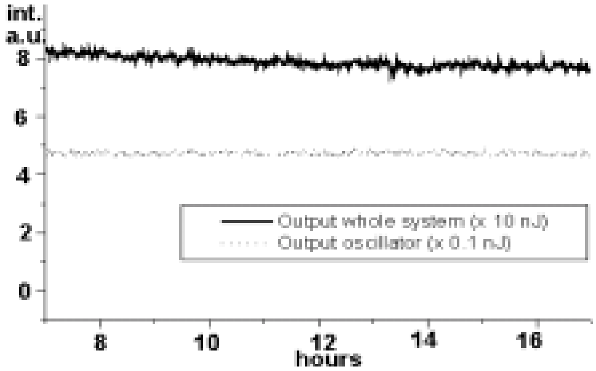

Fig. 4.: PHELIX ns-frontend long term energy stability.

AWG is shown together with the optical output of the laser beam measured by a fast photodiode. The chosen pulse shape was similar to a ‘Haan’ type pulse that is used in laser fusion experiments. The test results show a excellent response of the electro-optical system to the input signals. A total contrast ratio of 60 dB has been obtained, which is sufficient for further amplification up to the kilojoule level.

The components have been shipped to GSI and were re-activated successfully. The remaining parts, namely the phase

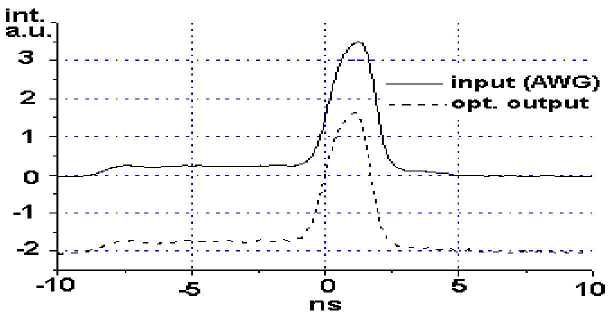

Fig. 5.: Performance test of the modulator section.

modulator and the fail safe system are currently under construction at Livermore and will become operational within the year 2001. The regenerative amplifier is operational at GSI and will be placed into the PHELIX building for detailed performance tests.

Parts for the preamplifier section which will amplify these pulses up to the 10 Joule level are under preparation together with the Lawrence Livermore Laboratory.

In conclusion, the first parts of the PHELIX front-ends are operational with excellent performance and will be coupled to the following amplifier sections early in the year 2001.

References

[1] PHELIX Project, GSI-98-10 Report, December 1998

[2] PHELIX - A Petawatt High-Energy Laser for Heavy-Ion Experiments, R. Bock et al., Inertial Fusion Sciences and Applications 99, C. Labaune, W.J. Hogan, K.A. Tanaka Eds., Elsevier Publishing, Paris, Amsterdam, Lausanne, New York, Oxford, Shannon, Tokyo (2000) 703

[3] PHELIX – ein Petawatt-Hoch-Energie-Laser, Th. Kühl, Phys. Bl. 5 (2000) 49