

PHELIX Progress Report

V. Bagnoud^{1,2}, A. Blazevich¹, R. Bock¹, S. Borneis¹, H. Brand¹, C. Bruske¹, J. Caird⁸, U. Eisenbarth¹, J. Fils^{1,2}, R. Fuchs¹, S. Götte¹, M. Hagemann^{1,3}, T. Hahn¹, H.-M. Heuck^{1,4}, C. Hildebrandt³, D. H. H. Hoffmann^{1,2}, D. Javorkova¹, H.-J. Kluge¹, F. Knobloch¹, Th. Kühl^{1,5}, S. Kunzer¹, M. Kreutz¹, R. Lotz¹, T. Merz¹, P. Neumayer^{1,6}, E. Onkels¹, D. Reemts¹, M. Roth^{1,2}, H. Schmidt³, C. Spielmann⁶, R. Stenner¹, A. Tauschwitz¹, R. Thiel¹, U. Thiemer¹, D. Ursescu¹, K. Witte¹, U. Wittrock⁴, B. Zielbauer^{1,7}

¹GSI, Darmstadt, Germany; ²Technische Universität Darmstadt Germany; ³Fachhochschule Darmstadt, Germany; ⁴Fachhochschule Münster, Germany; ⁵Universität Mainz; ⁶Universität Würzburg, Germany; ⁷Max-Born-Institut, Berlin/Germany, ⁸Lawrence Livermore National Laboratory, USA.

Abstract

We report the progress of the physics and engineering design effort and the construction of PHELIX, which will be capable of producing pulses up to the peak power of 10^{15} W (1 PW) in 500 fs and the energy of 4 kJ in 10 ns, respectively.

The PHELIX Mission

GSI Darmstadt is currently building a Nd:glass Petawatt High-Energy Laser for Ion eXperiments called PHELIX. The project is established in close cooperation with Lawrence Livermore National Laboratory (LLNL) in the US and the Commissariat à l'Énergie Atomique (CEA) in France. PHELIX will offer the unique combination of a high-current, high-energy (GeV/u), heavy-ion beam with a powerful laser beam thus providing the opportunity to investigate a variety of fundamental science issues in the field of atomic physics, nuclear physics, and plasma physics. Fig. 1 shows the schematics of the PHELIX PW-version. PHELIX is a member of the Laserlab Europe and the Optence network.

Pulsed power system and Timing

The PFN and control system of the preamplifier consisting of 2x19 and 1x45 mm diameter rod amplifiers (see Fig. 1) were changed to comply with the VDE safety standards and successfully put into operation. Extensive operation tests of the main amplifiers were performed. The electrical system was tested by discharging several times all capacitors for the double-pass amplifier simultaneously into dummy resistors at the full charging voltage of 18 kV. Modifications in the amplifier housings were checked to withstand the intense pump light pulses in a series of 50 shots at full energy for each amplifier. After an improvement of the cleaning procedure, all amplifiers passed the test which was done without laser disks.

During these tests, two out of the 100 flash lamps failed to ignite and were disconnected from the capacitor bank for the rest of the tests.

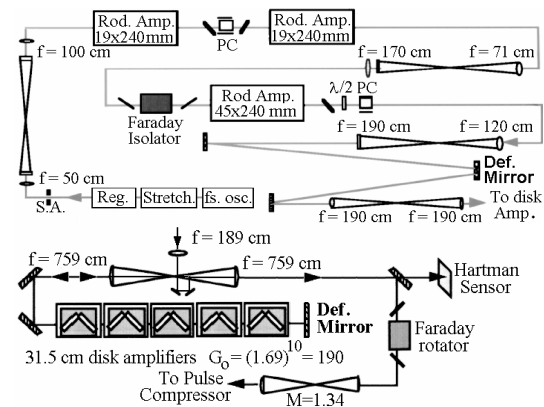


Figure 1: Schematics of the PHELIX PW-version. The front-end comprises the oscillator, stretcher, and two regenerative amplifiers. The pre-amplifier includes two 19-mm rods, one 45-mm rod, and four telescopes. The main amplifier consisting of five sections each containing two disks is double-passed.

Although 98% of the more than ten years old flash lamps survived, it was decided to replace them all since a visual inspection revealed a large number of cracks in the quartz tubes of almost each lamp. New flash lamps were specified and ordered with an expected delivery time April 2006. The setup of a dedicated test stand for the acceptance test of the new lamps was started in order not to interfere with the extensive testing procedure with the setup of components in the laser bay.

To ensure synchronized operation of PHELIX with the accelerators at GSI, the communication hardware

for the timing systems of UNILAC, SIS, and ESR were installed and the synchronization scheme was further finalized. To improve the long-term stability of the timing system, some critical connections to the accelerator timing were replaced by fibre optical connections which will ensure a stable synchronization to better than 1 ns under all circumstances.

Controls

The PHELIX Control System (PCS) is based on the framework of the CS which is in-house developed by the EE/KS group. In 2005, the PCS has grown up to about 30 PHELIX specific classes. About 700 Boolean and analogue values are read out or can be set by the PCS until now. The PCS is running distributed on about ten personal computers. The general architecture of the PCS is worked out. Important parts are already realized. According to the concept of object orientated programming, first the device layer instances are programmed which interact each with one device. Some of them are combined in application layer instances. These instances control the sequences of subunits. Thus the machine safety is guaranteed. On the highest level, the user interacts via an easy GUI. The necessary interfaces are implemented to add subsystems piece by piece according to the progress of hardware construction work.

In 2005, the main focus was the remote control of the pulsed power system which is a good example for the principle explained above. Device layer instances such as an electrical power supply unit, some high-power switches, diagnosis and so on are combined to a power unit (application layer) which pumps a laser head. Until now, six of these are running for the main amplifier section, while the preamplifier consists of four of these units. The shot sequencer of PHELIX controls all these units. From respect to the control system, the pulsed power system is ready to operate.

In 2006, the control system will focus on optical diagnosis and laser position monitoring and stabilization. A data collector documenting the shots and a data base storing default settings will follow to ease the operation of PHELIX. Finally the connection to the different experimental areas and the synchronization with the ion beam has to be set up.

PW compressor

In 2005, major milestones have been covered for the PW compressor. First, the compressor optical layout has been frozen offering the best trade-off between performance, cost, space, and versatility. The compressor will be hosted in a vacuum chamber. This chamber has been ordered in 2005; its fabrication has started and extends into 2006. It is made of two cylinders, connected by a middle piece and many

flanges to allow the beam to get in and out. A top view of the chamber is presented in Figure 2. The chamber will first be installed in the laser bay to allow for its qualification and experimental suitability.

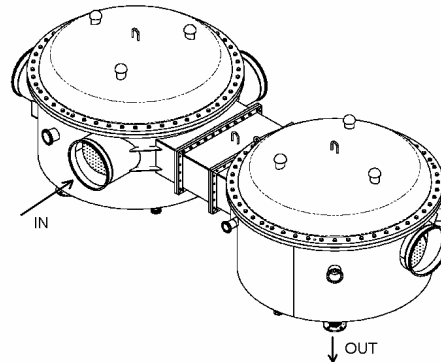


Figure 2: The Petawatt compressor tank.

Beam diagnostics

To characterize the fs-pulse precisely, we have developed a second-order scanning auto-correlator with a high-dynamic range serving as a pulse length etalon.

The diagnostic of the 28-cm beam of ns duration includes its total energy, its near- and far-field fluence patterns, and its wave front. The turning mirror following the 1:1 telescope (see Figure 1) has the transmission of 1%. The transmitted beam is first down-collimated in two steps to the diameter of 22 mm. A beam splitter then reflects 90% of the pulse energy into a calorimeter. The transmitted portion passes an attenuator whose dynamic range can be well matched to full power shots of 1-kJ energy and to low-power shots of much less energy as well such that the subsequent sensors recording the near- and far-field fluence patterns and the wave front can always be operated under optimal conditions.

The near-field sensor (Basler 601f digital camera) receives a real image of the actual beam de-magnified by the factor of 125. The far-field fluence pattern is recorded simultaneously with low and high resolution. The low-resolution image is for beams with relatively large phase front errors; it is obtained by placing the focus of the imaging lens directly on the camera chip (Basler 601f) yielding spot sizes of 30- μm . In the high-resolution case, the focal pattern is imaged onto the camera chip (Basler 601f) by a microscope objective providing the magnification of ~ 100 . The wave front is measured using a Shack-Hartmann sensor that receives a real image of the actual beam de-magnified by the factor of 80. Aberrations as small as $\lambda/10$ can be measured.

Except for the energy calorimeter, the full diagnostic system has been successfully tested using an

auxiliary laser so that it is ready for the characterization of PHELIX pulses.

Simulations with Miró

We have continued simulations of the pulse propagation in PHELIX using the code Miró [1]. Particular attention was paid to super-Gaussian beams with elliptical cross section selected to optimally fill the rectangular compressor gratings. Two further issues concerned the effect of static aberrations of the optical components comprising the main amplifier including the disks, turning mirrors, 1:1 telescope, and Faraday rotator on the size of the pinhole in the telescope and the capability of the bimorph mirror placed behind the preamplifier (see Figure 1) to correct these aberrations. It turned out that the pinhole diameter has to be increased only slightly to avoid plasma formation. The focusability is more seriously affected by the aberrations as can be seen in Figure 3 showing three intensity profiles in the focal plane of the telescope following the double pass in the main amplifier. The aberrations reduce the Strehl ratio, ρ , to 0.58. However, it can be almost fully recovered by the bimorph mirror leading to the conclusion that the static aberrations do not impair the PHELIX performance. Thermal aberrations and means to minimize their effect will be investigated next.

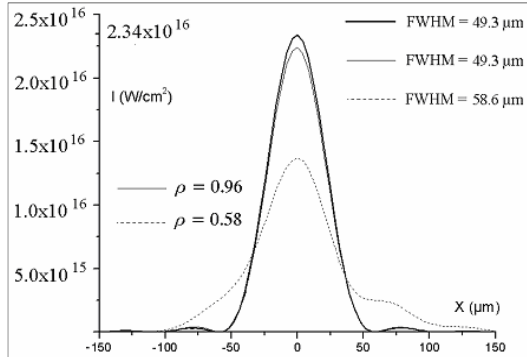


Figure 3: Intensity profiles along the x-axis for an aberration-free beam (thick solid line), for a distorted beam (dotted line), and for a corrected beam (thin solid line). The corresponding full width at half maximum (FWHM) and the Strehl ratio, ρ , are also given.

In-situ inspection of large-sized lenses

The 1:1 telescope following the main amplifier serves for image relaying and simultaneously for spatial filtering as well thus requiring vacuum. Since outside the telescope atmospheric pressure prevails, the lenses have to withstand a difference pressure of 1 bar. Due to their large diameter of 520 mm, fracture is a non-negligible risk. By in-situ inspection of the

lenses before and after each shot, surface and bulk damages usually preceding fracture can be detected.

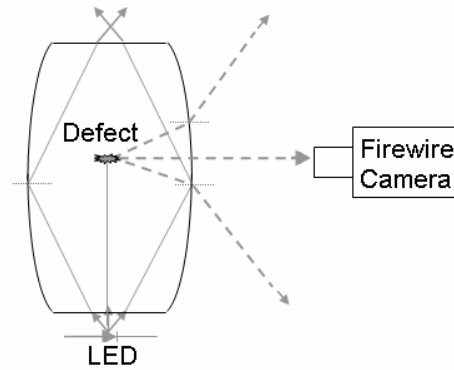


Figure 4: Sketch of the experimental setup. A defect in the middle of the lens is assumed to be present.

The inspection is made by the combination of an illuminating system and an image processing system both specifically designed for this purpose. The lens interior is illuminated by a couple of LEDs located in the lens holder as indicated in Figure 4. The setup relies on total internal reflection of the LED light entering the lens through its perimeter by the polished lens surfaces so that it is internally flooded with light. Imperfections inside the lens will scatter the LED light in all directions by acting as point-like sources. The high-resolution firewire camera looking either onto the front or back surfaces of the lens catches a fraction of this scattered light. It has been proven that defects with scale lengths >0.46 mm can be safely detected this way.

The image processing code written in LabView takes a reference image before each laser shot that is subtracted from the image taken after the shot. Thereby any changes resulting from the laser irradiation become visible. If there is any damage, it is marked on the on-line image that is then saved for further processing.

References

- [1] O. Morice et al., *Miró V5E: Reference Manual*, CEA Internal Publication, October 2002.