PHELIX – A Petawatt High-Energy Laser for Heavy-Ion Experiments – Status Report

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The recently started PHELIX project will supplement the high-intensity heavy-ion beams available in the near future at GSI by the installation of a kilojoule/petawatt laser system. Essential for a wide applicability of this laser system is its versatility in the temporal duration of the laser pulses. It is therefore planned to build a laser system that can be operated as a kilojoule laser with either nanosecond or sub-picosecond pulses. The project is in collaboration with the Lawrence Livermore National Laboratory and the Max Born Institute in Berlin [1]. In combination with the recent intensity upgrade of its accelerator facility PHELIX will provide for GSI a unique combination of a high-current, high-energy (GeV/u) heavy-ion beam with an intense laser beam. Attractive combinations of a high-energy laser and a heavy-ion beam are visualized in fig. 1. Both the laser and the heavy-ion beam can be used to produce plasmas of exceptional properties as illustrated by the picture inserts. Alternatively they can serve in specific way for the diagnostics of such plasmas. This alone provides a number of outstanding experimental possibilities. This potential is additionally increased by the proven and improved capability of the GSI heavy-ion accelerators to provide a large variety of highly charged ions and radioactive isotopes. These can be used for novel atomic and nuclear physics experiments, in particular in combination with the ultra-intense pulses of the petawatt option.

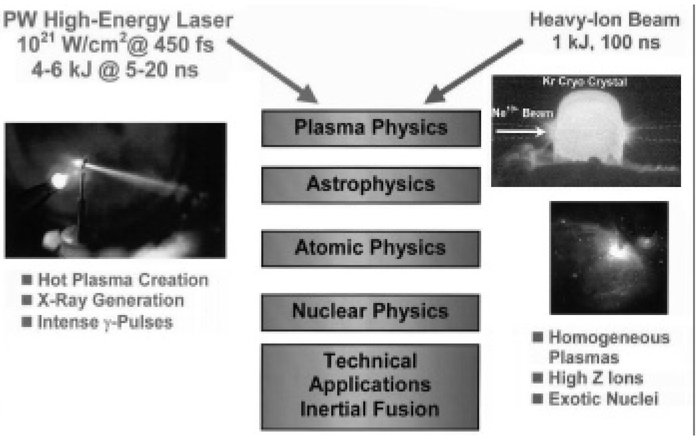

Figure 1: Combined use of heavy-ion and laser beams

Construction of the laser building, situated between the UNILAC experimental hall and the ESR hall, has started in December 1999 (fig. 2). The building presents about 400 m^2 of floor space on the ground level, reserved for the laser set-up. A clean-room environment of class 10000 will be provided within this area. The foundation is a 90 cm thick layer of concrete, sufficient to suppress the typical sole vibrations measured on the site. Capacitor banks, the control room and a class 1000 clean-room for the preparation of laser components are situated on the second floor of the building. A steel-frame tower will serve to hold the beam-line components to provide a stable beam transport into both the UNILAC experimental hall and the ESR hall. Completion of the building is expected for July 2000.

Figure 2: Ground-breaking for the PHELIX building was performed on December 7th 1999 by Staatssekretär Frank E. Portz of the Hessisches Ministerium für Wissenschaft und Kunst together with the Scientific Director of GSI Walter F. Henning.

The basic layout of PHELIX has been changed from the original design to use solely 31.5 cm amplifier heads. It consists of the following components:

1. A versatile *front-end* that provides options for a variety of pulse shapes of width between 1 ns and 20 ns at 50 mJ output.
2. A dedicated short-pulse front-end capable to produce pulses of 50 mJ of a duration between 200 fs to 300 fs stretched to > 1 ns.
3. A *preamplifier* to increase the pulse energy from both these sources to around 10 J.

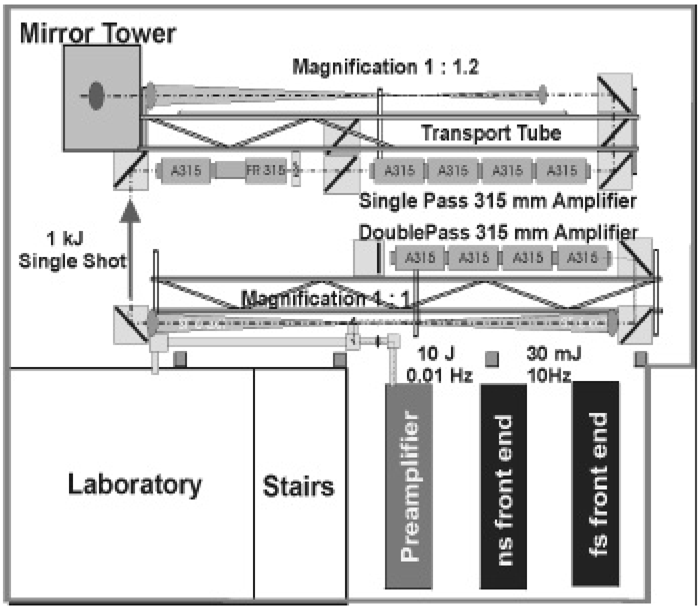

Figure 3: Layout of PHELIX

4. *A one-kilojoule amplifier* with two-pass architecture using four 31.5 cm disk amplifiers from PHEBUS and NOVA.
5. A *booster* section with additional four 31.5 cm amplifiers.

The sub-picosecond option employs a stretcher-compressor set-up for chirped pulse amplification (CPA).

A sketch of the planned laser arrangement in the first floor of the new laser building is given in fig. 3. It shows the lay out of the main amplifier and the position of the ns- and fs-front-ends, and the preamplifier stage.

In contrast to the original design, the new concept for the main amplifier comprises of a double-pass section and a single pass booster section, both using amplifiers with 31.5 cm beam aperture. This change was motivated mainly by the availability of parts from the decommissioned NOVA and PHEBUS systems. An advantage of this design over the idea to use 20.8 cm components in the first section is the reduction of flux. This is of importance for the amplification of the chirped pulse for the petawatt option. The performance analysis of the design shows the following characteristics: already after the double-pass section pulses of approximately 1 ns duration can be delivered with pulse energies up to 600 J, as needed for the petawatt-option. For pulses longer than 10 ns energies up to 1 kJ can be tolerated by all components, and could be achieved by increasing the preamplifier output to 15 J. Using a second group of four 31.5 cm amplifiers as a booster, the output power for these longer pulses can be increased to 4.2 kJ. This group will be bypassed for petawatt operation. A further increase of the respective energy levels to 1 kJ without and 5 kJ with the booster amplifiers can be reached by inserting a single additional amplifier unit outside of the double pass section.

The femtosecond-front-end, shown schematically in fig. 4, is nearing completion as a customized laser system by a commercial vendor. It uses a commercial Ti:Sapphire femtosecond oscillator pumped by a single-mode Nd:YVO$_4$ laser. The pulse from this laser is stretched in a grating device. This longer pulse is amplified in two so-called regenerative amplifiers pumped by pulsed Nd:YAG lasers to an energy level of 50 mJ.

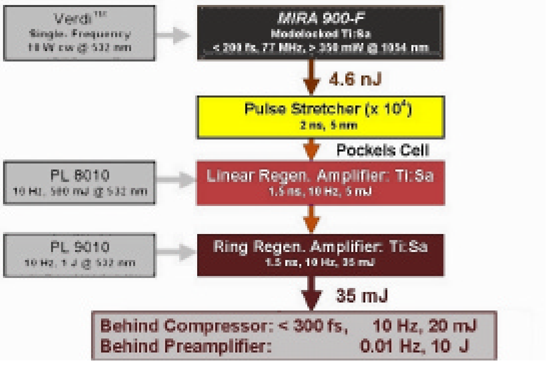

Figure 4: Schematics of the femtosesond front-end

The scheme of the nanosecond-front-end depicted in fig. 4 has close similarity to the front-end for NIF, the National Ignition Facility under construction in Livermore. A fiber-laser oscillator is followed by fiber modulators and fiber amplifiers. Most of the necessary components are delivered. To reach the 50 mJ level a flash-lamp pumped large aperture ring amplifier is foreseen.

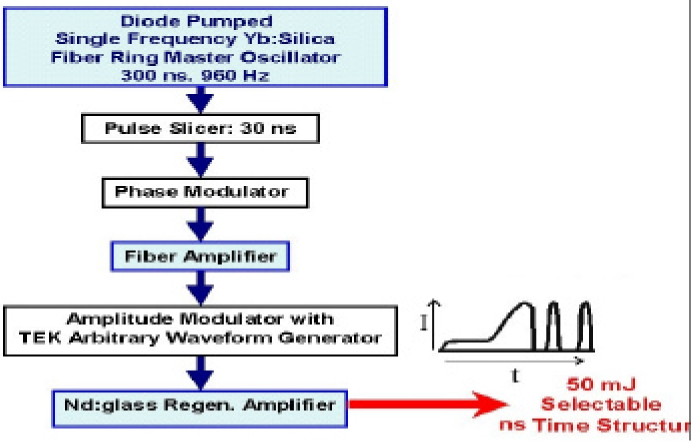

Figure 5: Schematics of the nanosecond front-end

For the preamplifier system two flash-lamp pumped Nd:Glass amplifier heads with 19 mm beam diameter and larger amplifier with 45 mm aperture are necessary. The 19 mm heads have been designed in collaboration with LLNL and Big Sky Laser Industries, Bozeman Montana. These amplifiers will allow a maximum repetition rate of 0.5 Hz and support a pulse energy of 2 J. A first approach for the 45 mm head follows the design of the LLNL Petawatt laser [2], and is capable to allow one pulse every 100 seconds. An amplifier head supporting a much higher repetition rate is under preparation at MBI.

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

[2] D. Pennington et al., Proceedings of SPIE, The International Society for Optical Engineering, vol. 3047, 490 (1997)