Annual Report

Funding Programme:	**Helmholtz Joint Research Groups**
Project ID No.:	HRJRG-400
Project Title:	Application of 3D ellipsoidal cathode laser pulses for high brightness photo injector optimization
Principal Investigator:	Dr. Mikhail Krasilnikov (Helmholtz PI) Prof. Efim Khazanov (Russian PI)
Report Period (=Calendar Year):	01/2016-12/2016

1) Group Structure

Please report briefly on the structure and personnel development of your group.

Helmholtz Association group (Germany):

DESY, Zeuthen site:

- Dr. Mikhail Krasilnikov (PI), general coordination, beam dynamics simulations, PITZ run coordination; scientific supervision;
- Dr. Frank Stephan (senior scientist, DESY), head of the accelerator activity in Zeuthen and PITZ group leader, general coordination, scientific supervision;
- Dr. Yves Renier (postdoc at PITZ, DESY), beam dynamics simulations for various shapes of the photocathode laser pulse, simulation of expected experiment at PITZ;
- Dr. Tino Rublack (postdoc at PITZ, DESY), photocathode laser expert, responsible for the PITZ laser room infrastructure, responsible for the new laser system tuning and redesigning from DESY side;
- Dr. Matthias Gross (senior scientist, DESY), photocathode laser expert; simultaneous operation of two photocathode laser systems at PITZ;
- Prach Boonpornprasert (PhD student at PITZ, DESY), investigations on the capabilities of THz production at the PITZ facility, start-to-end beam dynamics simulations for various shapes of the cathode laser pulse;
- James Good (PhD student at PITZ, DESY), commissioning of the new laser system at PITZ, laser pulse shaping experiments, experimental characterization of laser pulses and electron bunches generated from the new laser system, ZEMAX simulations

Russian participants:

IAP, Nizhny Novgorod:

- Prof. Efim Khazanov (PI), general coordination, scientific supervision;
- Dr. Anatoly Poteomkin (senior researcher), scientific supervision, laser amplifiers, beam transport lines, nonlinear optics, general scheme of the laser;
- Dr. Sergey Mironov (scientific researcher), general coordination, numerical simulations of the laser pulse properties, harmonics (SH and UV) generation, modelling of cross-correlator operation;
- Dr. Ekaterina Gacheva (scientific researcher), multi-pass broadband Yb:KGW amplifier, delivery system of the diode pump, laser system assembling and adjustment, system of beam diagnostic;
- Victor Zelenogorsky (scientific researcher), laser pulse shaper, automation of the pulse shaping algorithm, cross-correlator for 3D shape diagnostics, spatio-temporal measurements;
- Dr. Maryana Kuzmina (scientific researcher), laser pulse shaper.

JINR, Dubna:

- Dr. Evgeny Syresin (group leader), beam dynamics, formation of high power electron beam in FELs, diagnostic of electron bunches in FEL;
- Dr. Sergej Kostromin (scientific researcher), developing of accelerator technique;
- Roman Makarov (engineer), development of diagnostic technique for FEL;
- Dmitry Petrov (engineer), development of undulator system applied for longitudinal shape of ellipsoidal electron bunches.

2) Network/ Meetings

Please describe how the group works together. Have there been any international meetings organized by or attended by the group? What is the contribution of the group to the networking of international partners and the Helmholtz Centre?

Nonlinear waves-2016, Nizhniy Novgorod, Russia, 27.02-04.03.2016

- M. Krasilnikov “High brightness RF photo injectors for modern Free Electron Lasers.”

2nd Annual MT Meeting, Karlsruhe: 8 - 10 March 2016

- P. Boonpornprasert et al., „First Experimental Characterization of Electron Beams for THz Options at PITZ

DPG-Frühjahrstagung (Spring Meeting), Darmstadt: 14-18.03.2016

- P. Boonpornprasert et al., „First Characterizations of a 4 nC Electron Beam for THz Options at PITZ”

PITZ Collaboration Meeting, Zeuthen, 31.05-01.06.2016

- E. Khazanov "Photocathode laser developments",
- J. Good “Laser System for Generation of Quasi Ellipsoidal Pulses”
- M. Nozdrin “JINR: e-Linac and Photoinjector Activities”

Senior scientific researcher qualification seminar, IAP RAS, June 2016

- S. Mironov "Control of spatial and spectral-temporal parameters of femtosecond laser pulses"

PITZ Collaboration Meeting, Zeuthen, 29.11-30.11.2016

- S. Mironov "Laser pulse shaping activity in IAP RAS"
- J. Good “ELLA status”

Collaboration meetings between IAP RAS, PITZ and FS-LA (DESY Hamburg) experts:

04.03.2015 IAP RAS, Nizhniy Novgorod
M. Krasilnikov, DESY (PITZ)
A. Andrianov, E. Gacheva, E. Khazanov, S. Mironov, A. Poteomkin, IAP/RAS

13.04.2016 Skype-conference DESY
J. Good, M. Gross, M. Krasilnikov, T. Rublack, DESY (PITZ)
L. Winkelmann, DESY, Hamburg

22.11.2016 PITZ, DESY,
J. Good, M. Gross, M. Krasilnikov, T. Rublack, F. Stephan, DESY (PITZ)
S. Mironov, A. Andrianov, E. Gacheva, IAP (Nizhny Novgorod)

14.12.2016 Skype-conference DESY-IAP
J. Good, M. Krasilnikov, T. Rublack, M. Gross, DESY (PITZ)
A. Andrianov, E. Gacheva, S. Mironov, A. Poteomkin, IAP/RAS

Visit of IAP experts for the laser system tuning:
21-29.11.2016 S. Mironov, A. Andrianov, E. Gacheva

3) Scientific Progress / Milestones
How has your work plan progressed? What important milestones could be achieved during the report period? Is the progress of your work in accordance with original planning or has the work plan been changed?

Helmholtz Association – DESY, Zeuthen site:

ELLA Laser system at PITZ

After the installation and generation of ultraviolet laser pulses in December 2015 commissioning and testing of the new Ellipsoidal Laser (ELLA) system began. A number of technical issues, which were overlooked during development or newly developed, were encountered during this time and therefore most of the progress with the system has been technical [1]. Nevertheless at the end of the year it was possible to start measurements with electron beams.

Major difficulties found in 2015 have been an incompatibility of the laser system as well as the spatial light modulators (SLM's) with the main timing system of the PITZ accelerator. As a very precise synchronization of the photo cathode laser compared to the RF of the accelerator is crucial for the operation of facilities like FLASH and the European XFEL, the most important task in 2016 had been the development and afterwards the commissioning of a uTCA timing crate (Fig. 1, left), which allows such very accurate synchronized laser pulse generation within the laser oscillator (part of work package WP6). The synchronization works two-level (Fig. 1, right). Rough synchronization can be done by a controlled change of the temperature within the laser oscillator. This allows an accuracy of about few kHz. The fine tuning of the frequency can be done afterwards by applying a voltage to a piezo drum which is embedded in the laser oscillator. At the end of 2016 synchronization tests showed that the uTCA is reliably working 24/7 without any disruptions.

Fig. 1. uTCA board (left) used for the laser pulse synchronization and its principal schematics (right).

As found out in 2015 the Holoeye SLM installed at first in the laser beam line had to be exchanged to avoid time-dependent fluctuations of the reflection coefficient of the device. After first tests done at IAP and detailed discussions with Hamamatsu SLM experts a time-independent SLM (LCOS-SLM Hamamatsu) produced by Hamamatsu was installed substitutional to the former one. In a series of experiments it could be verified that the new SLM fulfills all stability requirements defined by laser and accelerator experts.

Next to the synchronization and SLM issues DESY experts developed new devices for laser pulse characterization based on the IAPs spectrograph design. The first spectrograph to characterize the spatial and temporal laser pulse profile before harmonics generation has been installed and tested in 2016 (Fig. 2, left). A second one to do the same but after frequency conversion is under construction.

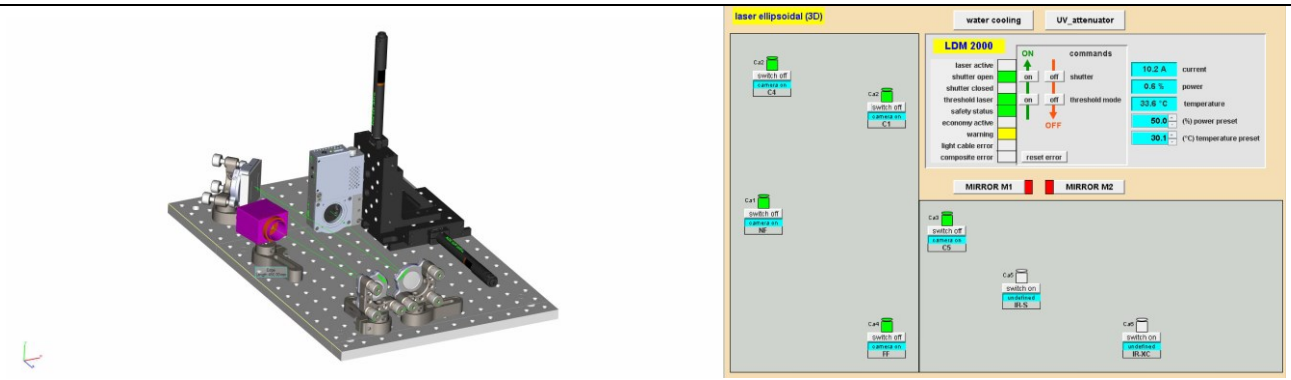

Fig. 2. CAD design of the IR spectrograph (left). ELLA GUI with TV system schematics (right).

Another important part of the work done in 2016 had been the commissioning of a beam pointing stabilization system. Even though the system is in general working, a routine operation is complicated by limited space. The installation of a TV system needed for laser pulse characterization has been finished. Also the embedding of the devices into the PITZ control environment has been finished (Fig. 2 right).

Experiences with the prototype have shown that significant upgrades (which is a part of the milestone R-MS3) of the laser system are needed in order to facilitate the installation of such a system at a full-time user facility, such as FLASH and the European XFEL. As a first step a new laser oscillator (Pharos by Light Conversion) has been ordered. This industrial laser should have several advantages: an amplifier is included which allows possible avoiding the disc-amplifier currently used, the laser frequency and the number of micro-bunches can be easily changed via control system, 2nd and 4th harmonics generation is possible without changing the system (which makes it useful also as a backup laser). Also an experience on the timing synchronization gained from the current system will be used. The delivery and installation is expected before Easter, 2017, its commissioning will start afterwards.

Actually, an optimized (in length and number of optical devices) redesign of the laser is under development using ZEMAX as simulation program and the installation will be done after the initiation of the Pharos laser system. Its principal schematic is shown in Fig. 3.

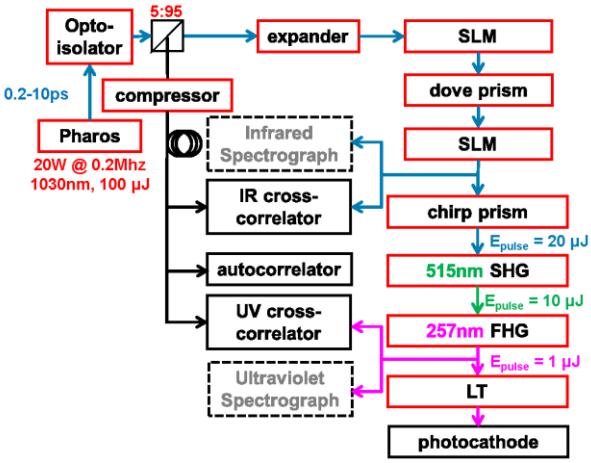

Fig. 3. Principal schematic of the upgraded laser system.

Parallel operation of two photo cathode laser systems at PITZ

One important technological issue for the photo injector optimization at PITZ is a compatibility of the new (ELLA) photocathode laser system with the existing (MBI) one. Efforts towards simultaneous

operation of both systems have been made. The photocathode laser systems are running simultaneously in the extended PITZ laser room. They are sharing a transport beam line to the photocathode. The switching can be done remotely by moving a dedicated mirror (Fig. 4). Currently, it takes several minutes to change the photocathode laser from MBI to ELLA and backwards. Still several adjustments (e.g. gun and booster nominal operation phases, ns-delays for LOW.ICT1 at ADC and BPMs) have to be done after selecting a new operation mode. Some improvements in the control system are still to be implemented for more automated switching procedure. A corresponding report (milestone H-MS5) is under preparation.

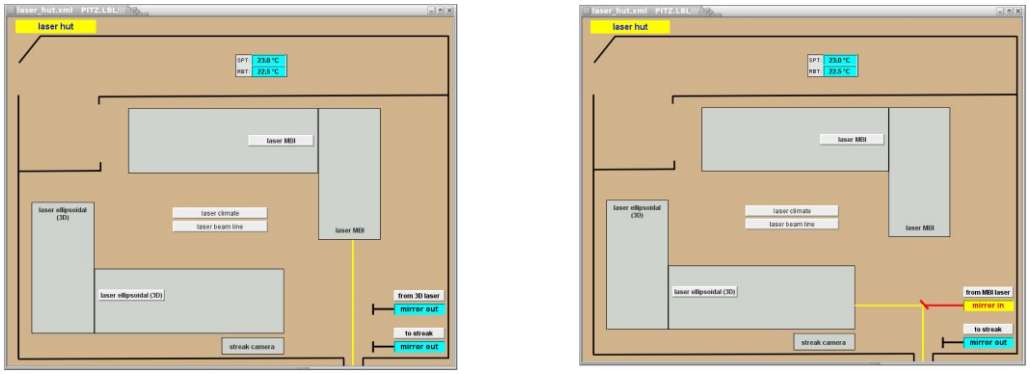

Fig. 4: PITZ photocathode laser control GUI: left – MBI laser pulses transported to the cathode, right – ELLA laser pulses transported to the cathode.

Besides the common transport line both laser systems share the diagnostics, e.g. the so-called virtual cathode camera (VC2) to measure the transverse distribution at a location optically equivalent to the real photocathode (Fig. 5)

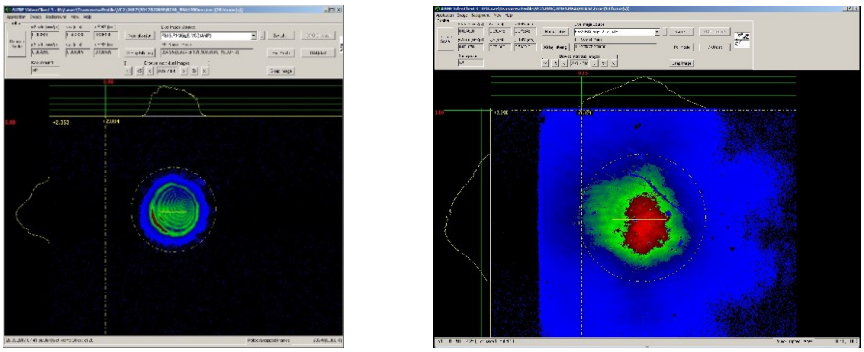

Fig. 5: Photocathode laser distributions captured by the VC2 camera: left - default (MBI) laser, right - ELLA laser pulse.

Photoemission studies at PITZ

Photoemission plays a significant role in the electron bunch formation processes. For high brightness photo injectors this process is complicated by the presence of strongly nonlinear space charge forces (including Coulomb force from the cathode image charge). Detailed experimental studies of charge extraction for various photocathode laser and rf gun parameters were performed at PITZ in combination with corresponding beam dynamics simulations. A “core+halo” model was developed for the transverse laser spot distribution at the photocathode. This model has significantly improved the consistency between simulated and measured bunch charges while laser and rf gun parameters were varied in a wide range. The results of these studies (milestone H-MS2) were summarized in the paper C. Hernandez-Garcia, M. Krasilnikov et al. “Studies on charge production from Cs2Te photocathodes in the PITZ L-band normal conducting radio frequency photo injector” [6] and in the PITZ internal note C. Saisa-ard “Evaluation of the photocathode laser transverse distribution” [7].

Simulations of electron bunch shape measurements for various photocathode laser pulse shapes

Electron bunch shape diagnostics with respect to the photocathode laser pulse shape is one of the important work packages of the project (WP5). Corresponding beam dynamics simulations on the measurement procedure have been performed. The note on 3D diagnostics of electron bunches at PITZ (milestone H-MS4) in under finalization. Simulations of the longitudinal profile measurement using a Transverse Deflecting Structure (TDS) have been performed for the PITZ setup with 3 photocathode laser shapes (Gaussian longitudinally and uniform transversely; flattop longitudinally and uniform transversely; 3D ellipsoid). As illustrated in Fig. 6, the TDS introduces a vertical kick which is proportional to the longitudinal position in the electron bunch. The beam image projection on the vertical axis at a downstream observation screen is used to measure the current profile.

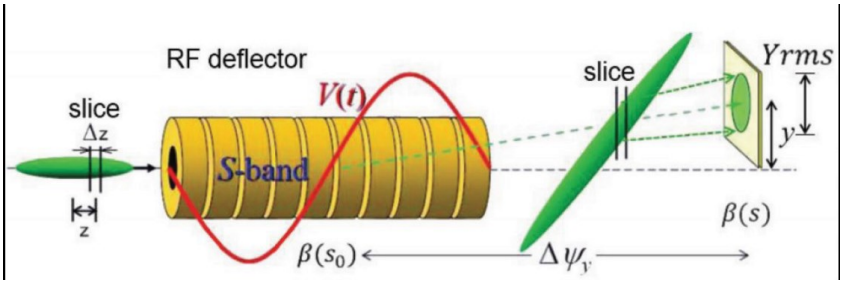

Fig. 6: Principle of a longitudinal measurement using the TDS.

The ratio of the vertical beam size with and without TDS at that screen gives the number of longitudinal slices which can be measured. As the TDS induces energy spread which is proportional to the vertical beam size in the TDS, to limit that energy spread, the optics were matched to obtain small vertical beam sizes in the TDS. Table 1 compares the longitudinal resolution and the obtained energy spread for the 3 laser shapes. The resolution is about 20um (~0.1ps).

laser	sigma_y (mm)		slice energy spread (keV)		longitudinal resolution (um)
TDS	off	on	off	on	on
ellipsoidal	0.041	4.1	1.2	30	20
flattop	0.050	1.3	2.0	42	23
Gaussian	0.047	3.9	2.1	50	24

Table 1: Vertical beam size and slice energy spread with TDS on or off. The longitudinal resolution is also calculated.

Fig. 7 shows the electron bunch current profiles, the beam side views and the simulated beams on the observation screen with TDS on for the 3 laser shapes. The current profile measurement of the ELLA laser generated beam is similar to the Gaussian shape, which indicates that the current profile is probably not well suited for laser tuning. It is clear that the beam profile on the screen is a very good estimation of the beam side view. Also, the differences between the lasers are much stronger looking at 2D distributions (t ,x) downstream the TDS (with TDS on) that just only bunch current profile analysis.

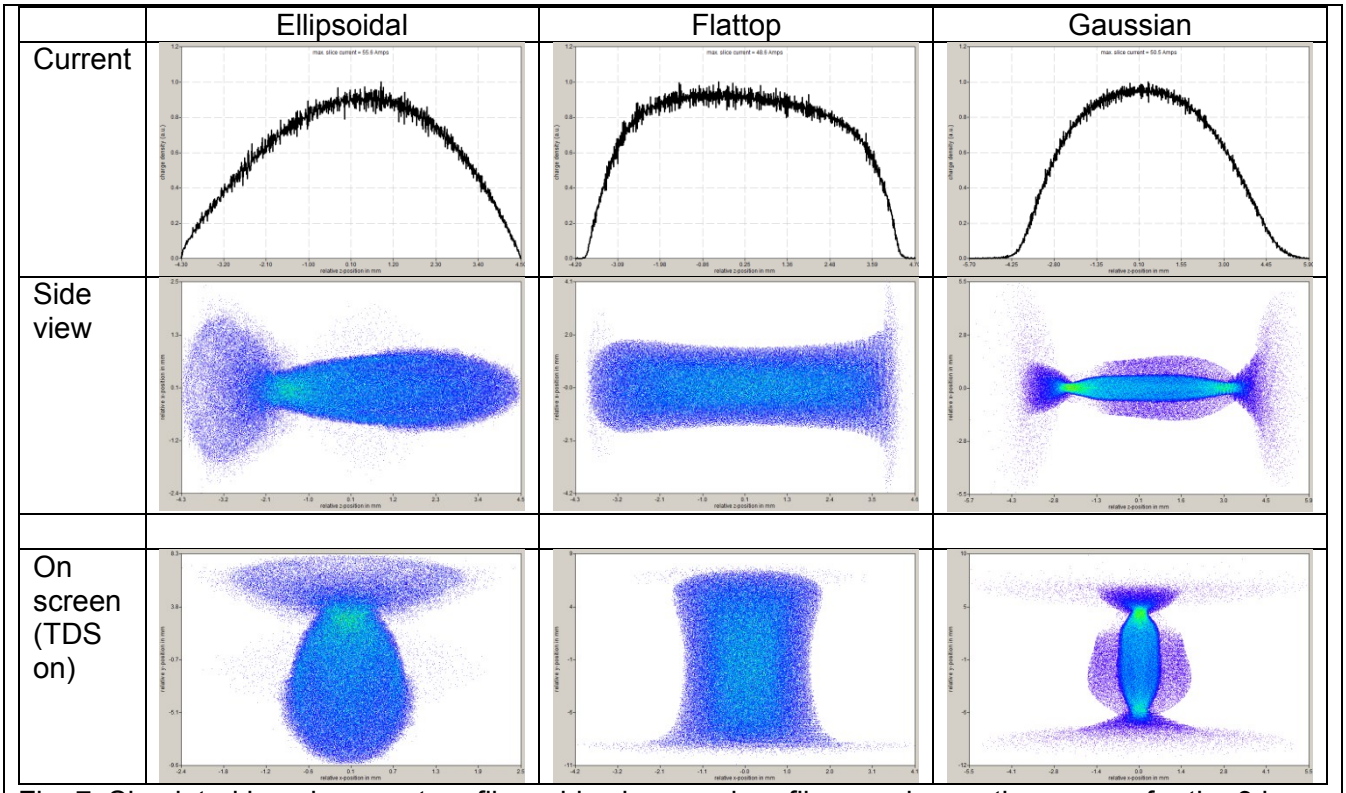

Fig. 7: Simulated bunch current profiles, side views and profiles on observation screen for the 3 laser shapes.

Progress on studies of the possibility to produce high power IR/THz radiation

As part of the beam diagnostics as well as a possible application of the new photocathode laser system a THz generation by specially shaped electron bunches is under study at PITZ. In 2016 experimental characterization and optimization of electron beams generated by the MBI laser system have been performed. Investigations on the capabilities of IR/THz production at the PITZ facility were continued. The IR/THz radiation generated by means of SASE FEL, Coherent Transition Radiation (CTR) and Coherent Diffraction Radiation (CDR) have been considered and studied. A long-Gaussian electron beam (~10 ps FWHM) with a peak current of ~200 A is used for the studies of the SASE FEL option. Electron beams with short-Gaussian (<2 ps FWHM) and comb-like longitudinal profiles are used for studies of the CTR and CDR options. Results of beam dynamics simulations and radiation calculations for these options were already presented in the previous annual reports. In 2016, experimental characterizations and optimizations for these types of electron beams were performed by using the MBI photocathode laser system (Cylindrical pulse shape).

Experimental characterizations of 4 nC electron beams, including current profile, transverse slice emittance and slice momentum spread, were done with beam momenta of 15 MeV/c and 22 MeV/c. The results are shown in Fig. 8. Corresponding IR/THz SASE FEL calculations using the GENESIS1.3 code based on the measured beam parameters are shown in Fig. 9. An APPLE-II undulator in Helical mode with period length of 40 mm was used as the radiator.

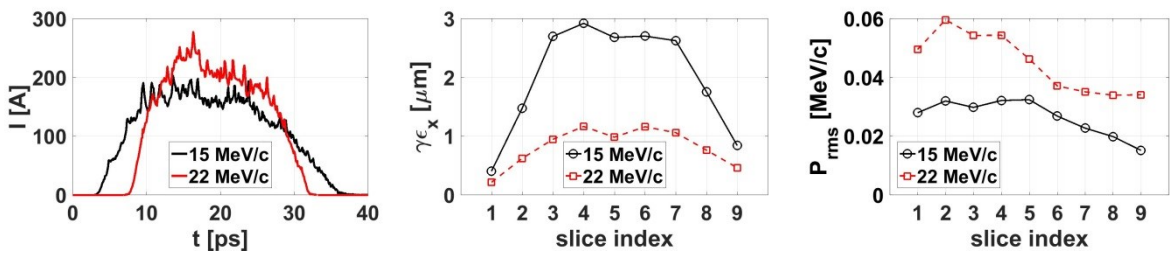

Fig. 8: Measured profiles of electron bunch current (left), slice emittance (middle) and slice momentum spread (right).

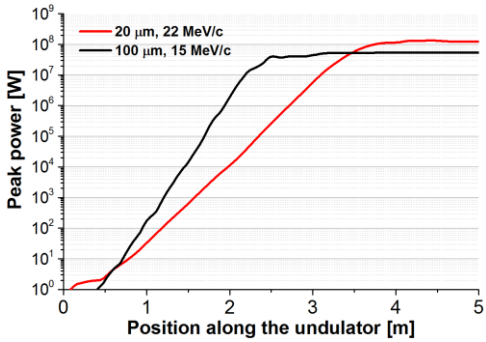

Fig. 9: Calculated SASE FEL using the GENESIS1.3 code based on the measured beam parameters. An APPLE-II undulator in Helical mode with period length of 40 mm was used as the radiator. The peak power at radiation wavelengths of 20 μm and 100 μm was calculated from the beam parameters for 22 MeV/c and 15 MeV/c cases, respectively.

Experimental optimization of electron beams for CTR/CDR options was done with 2 types of longitudinal laser profiles; short-Gaussian and comb-like. Both types of laser profiles were derived by adjusting the so called laser pulse shaper which consists of a set of 13 birefringent crystals. The electron beams were generated by illuminating the cathode with short-Gaussian (~2.5 ps FWHM) and comb-like (6 teeth) laser profiles for corresponding profiles of the electron beams. The electron bunches were compressed by changing the booster phase for velocity bunching. Fig. 10 shows the optimized beam profiles together with their corresponding calculated form factors. Results of CTR/CDR radiation pulse energy calculations from the optimized beam profiles are shown in Fig. 11.

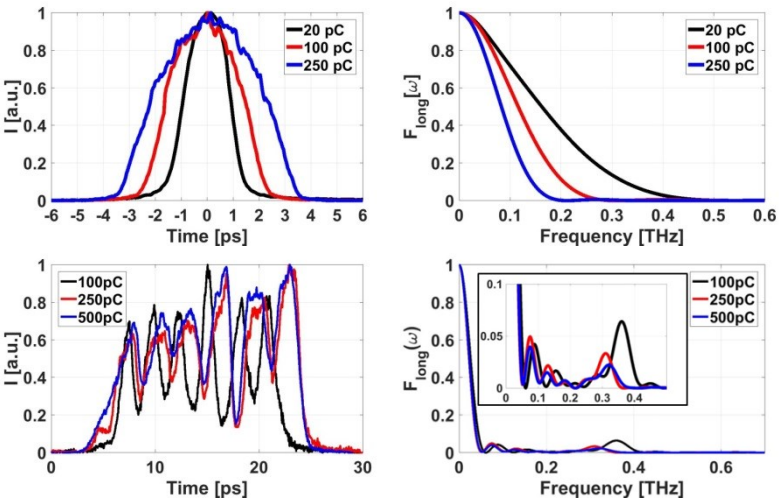

Fig. 10: Optimized bunch profiles (left column) and corresponding calculated form factors (right column) for the short-Gaussian case (top row) and the comb-like case (bottom row).

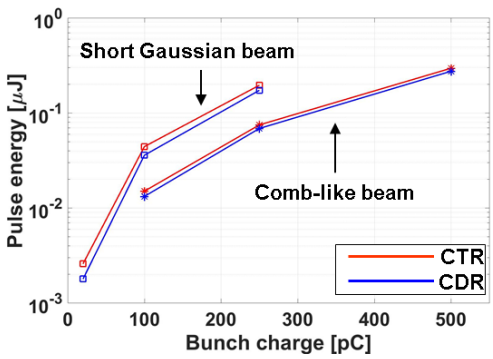

Fig. 11: Calculated total CTR and CDR pulse radiations from the optimized bunch profiles.

First electron beam generation with ELLA pulses

Realization of the laser to RF synchronization enabled first reliable and stable operation with photocathode pulses from the ELLA laser system. The first regular run period with ELLA at PITZ took place in December 2016. Several factors were still limiting the fine optimization of the photo injector with the ELLA laser. Not full matching of the laser beam into the common (with the default MBI laser) transport beamline led to a rather large laser spot size at the cathode (Fig. 5 right). So far no Pockels cell was available at that time; a pulse train of 300 pulses was always hitting the photocathode. Proper electron beam measurements were possible for some of the last pulses by corresponding adjustment of the diagnostics timing. This way several electron beam measurements were done.

The bunch charge was measured using the Faraday Cup (LOW.FC1), the results for 0.5 nC are shown in Fig. 12 (left). A gun phase scan for low charge is shown in the right plot of Fig. 12.

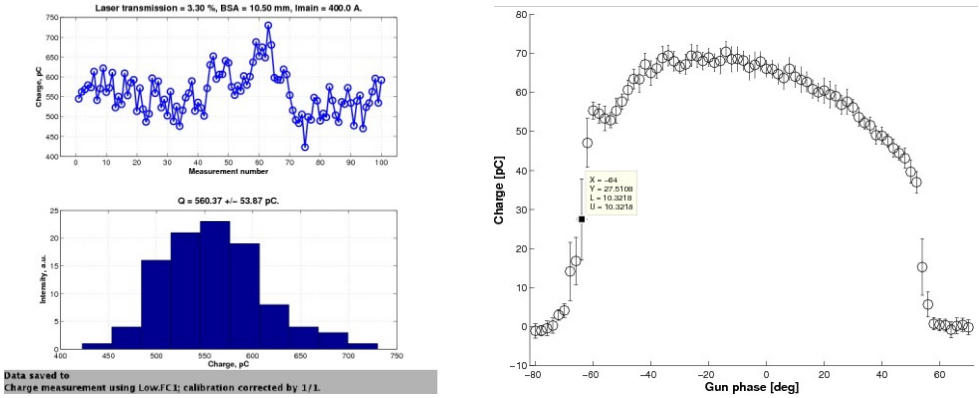

Fig. 12: Bunch charge measured at LOW.FC1 by applying ELLA pulses: 100 measurements done in 50 s for ~500 pC bunch charge (left) and gun launch phase scan for a bunch charge at lower laser pulse energy (~70 pC at the maximum).

The longitudinal momenta of the generated electron pulses were measured in the Low Energy Dispersive Arm (LEDA) as a function of the gun launch phase for a bunch charge of 0.5 nC (left plot in Fig. 13). The momentum distribution at LEDA measured at the phase of maximum mean momentum gain (MMMMG) is shown in the right plot of Fig. 13.

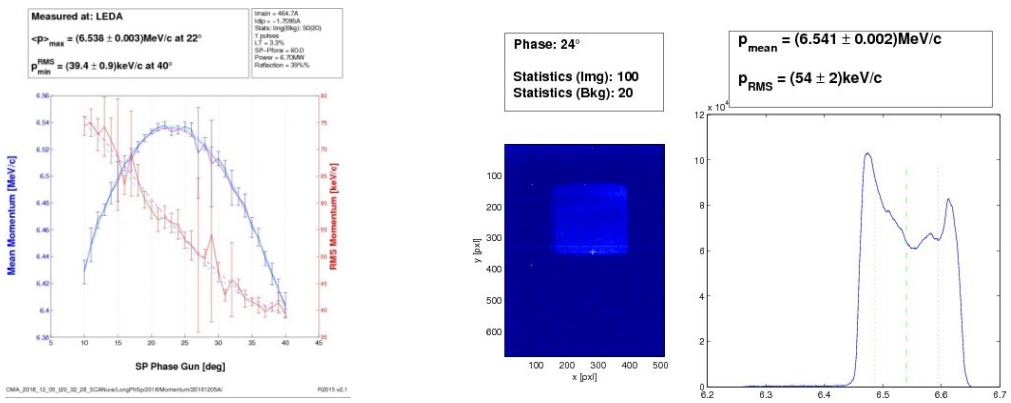

Fig. 13: Longitudinal momentum measured at LEDA: left - gun phase scan, right – momentum distribution at the MMMG gun phase.

Transverse distributions of 0.5 nC electron beam at the first diagnostic screen (LOW.Scr1, located at 0.8 m from the cathode plane) are shown in Fig. 14.

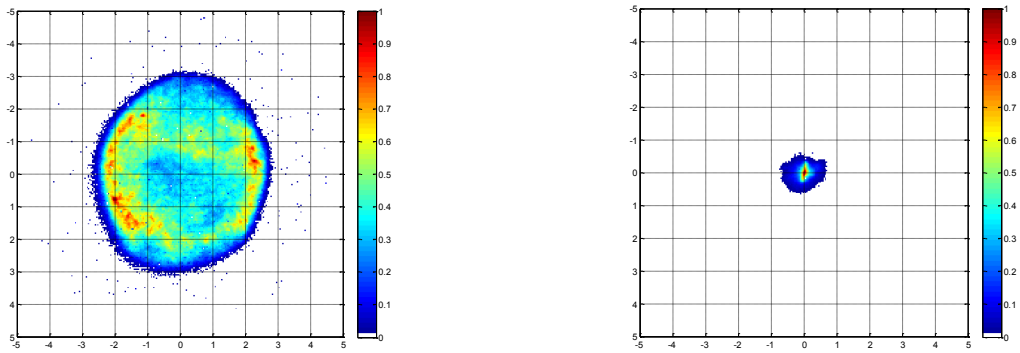

Fig. 14: Transverse electron beam distribution measured at LOW.Scr1 for 6.5 MeV/c mean momentum, 0.5 nC bunch charge and main solenoid current of 400 A (left) and 465 A (right).

Results of first preliminary measurements of the bunch current profile obtained with the Transverse Deflecting System (TDS) at PITZ for electron beams generated by ELLA pulses are shown in Fig. 15.

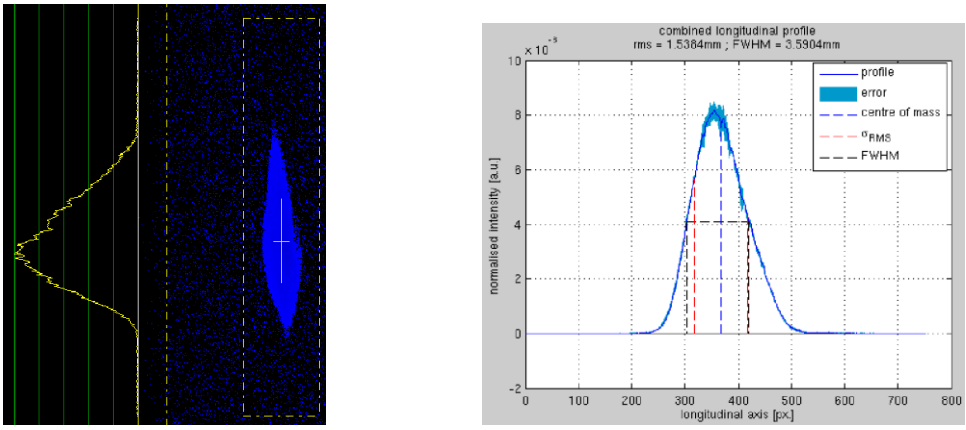

Fig. 15: Electron beam (bunch charge of 0.5 nC) at the PST.Scr1 streaked by the TDS. Left – electron beam distribution: vertical axis corresponds to the time. Right plot – obtained bunch current profile with ~12 ps FWHM.

First experiments with electron beams generated with photocathode laser pulses from the ELLA system demonstrated a possibility for experimental characterization including emittance and brightness. These experimental studies are ongoing now at PITZ.

Russian partners: JINR activities

JINR performed experiments in a test bench based on the 30 kV electron gun with a photocathode and a driver laser. The powerful laser driver developed by JINR-IAP collaboration and applied for the photo injector can be used in the FEL linear accelerator for a kW-scale EUV radiation. The laser driver operates at a wavelength of 260-266 nm.

A diagnostic technique applicable for FEL ultrashort electron bunches is developed at JINR within the framework of the PITZ and FLASH projects. Photon diagnostics are based on calorimetric measurements and detection of undulator radiation. The infrared undulator constructed at JINR and installed at FLASH is used for longitudinal bunch shape measurements (Fig. 16). The energy radiated by the far infrared (FIR) undulator is defined by the number of electrons per bunch and a form-factor. Measuring the radiation spectrum one can extract the form-factor and thus the charge distribution and the bunch length [5]. The reconstructed electron current pulse at FLASH at an electron energy 1.25 GeV and bunch charge 0.5 nC has a complicated shape with two peaks.

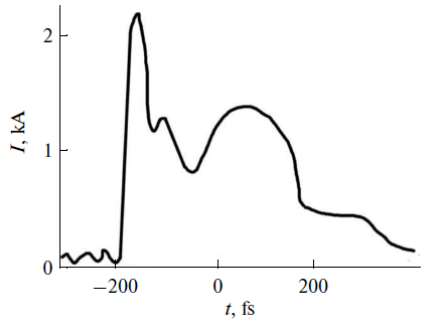

Fig. 16: Reconstructed from the form factor of the FIR radiation the time distribution of FLASH electron current measured from a single short electron bunch.

The new PITZ photocathode laser system is realized for optimized performance of the high brightness electron beam. The main goal is the production of 3D ellipsoidal electron bunches with homogeneous charge density. An electromagnetic wiggler is assumed to be used for measuring the longitudinal shape of such electron bunches at PITZ. The behavior of the form factor for 3D ellipsoidal bunches is qualitatively significantly different from the Gaussian case. Measuring of the form-factor permits to extract 3D ellipsoidal bunch shape imperfections which have essential influence on the beam emittance (milestone R-MS6). The wavelength range of the wiggler radiation is expected in the range 126 µm – 5 mm.

Russian partners: IAP activities

In 2016, laser experts from IAP RAS participated in joint works devoted to optimize the ELLA laser system parameters. At the experimental campaign in the period 21st-29th of November, 2016 the following experimental tasks were investigated:

a) Laser pulse energy jitter measurements of single laser pulses at different positions within the laser system. The jitter was measured to be:
   - After the fiber part 1.7-1.8% at the beginning of macropulse and 1.3-1.6% at the end
   - After Yb:KGW amplifier 2.6% at the beginning of macropulse and 1.6% at the end
   - After second harmonic generation stage 2.4% at the beginning of macropulse and 2.3% at the end
   - After UV generator: 3.1% at the beginning of macropulse and 0.8% at the end
b) Synchronization of ELLA laser system with the PITZ photo injector. The system was successfully synchronized
c) Measurements of the long term pointing stability. It was found in experiments that the pointing instability (drift) comes from the first part the laser system: between the output fiber collimator and the reference diaphragm. The instability was measured with a help of a CCD camera. Pointing jitter with total amplitude of 50 µm or less after more than 2 m laser beam propagation normally trends to equilibrium. The output fiber collimator is sensitive to temperature, humidity of air and other environmental parameters and it probably introduces the main impact to the pointing instability
d) Alignment of the laser system made it possible to obtain 90 mW (30 µJ in micropulse) in IR, 42 mW (14 µJ in micropulse) in green light, and– 3.2 mW (~ 1 µJ) in UV (works within the work package WP1)
e) The laser scheme improvement. After discussion with colleagues from DESY (PITZ) it was proposed to:
   - use a Pockels cell after the Yb:KGW amplifier for a single pulse operation mode of the laser system
   - implement a feedback between motorized mirrors and analyzer to compensate the drift of laser beam
   - use additional system for diagnostic of 3D intensity distribution of shaped laser pulses [3]. The optical scheme of a 3D image spectrograph was discussed and the spectrograph was assembled by DESY personnel.

- use Hamamatsu SLM instead of previously used Holoeye component. The Hamamatsu SLM was installed in the ELLA laser system. The first experiments on pulse shaping were done at PITZ.

As further development of advance photocathode laser pulse shaping technique a method of formation of 3D Quasi-ellipsoidal laser pulses with help of profiled volume chirped Bragg grating was suggested [4]. A 3D Chirped Bragg Grating (CBG) concept was developed in frames of the working package WP2 (3D laser pulse shape improvement).

Volume Bragg gratings, including CBG in photothermorefractive (PTR) glass, are widely used in different lasers thanks to their high diffraction efficiency, high damage threshold, and temperature and optical stability. The refractive index modulation period linearly changes along the direction of light propagation. In this case, different wavelengths are reflected from the grating at different depths, thereby introducing linear frequency modulation in the reflected beam.

For 3D ellipsoidal beam shaping we fabricated spatially profiled CBG. In such a grating, the region of transverse reflection for each wavelength is a circle with uniform reflection coefficient. The diameter of the reflection region changes depending on wavelength (longitudinal coordinate of the grating). At the boundaries of the reflection spectral band of the Bragg grating, the transverse size of the reflection region is minimal and for the central reflection wavelength it is maximal. Such a grating allows controlling the reflected beam diameter as a function of longitudinal coordinate. The coordinate is proportional to time and wavelength. These gratings were referred as 3D CBGs. They are made of standard CBGs by removing refractive index modulations from the grating areas where reflection is not needed. Reduction of the refractive index modulation amplitude is done by means of ultraviolet radiation with subsequent thermal processing to avoid damage of the produced 3D structure. In the present research we used a reflective 3D CBG produced by OptiGrate with the following parameters: aperture 6x6.3 mm, maximum ellipsoid diameter 6 mm, length 35 mm, central wavelength 1029.9 nm, FWHM spectral band 5 nm, and stretching factor 63.3 ps/nm. The reflection coefficient (diffraction efficiency) of the grating was measured as a function of transverse coordinate and wavelength (Fig. 17). Measurements were done by means of a superfluorescent LED. The CBG was placed on an XY linear translator so that the spectral profile of the reflection coefficient could be measured for the entire grating aperture. Reduced efficiency at central wavelength for the position 2 mm off the aperture center (see Fig. 17a) in comparison with the center position can be explained by finite diameter of the test beam of ~ 1 mm. The obtained data were used for calculation of the reflection coefficient spatial profile as a function of wavelength (Fig. 17b). As seen in Fig. 17b, the boundary of the reflection coefficient distribution of the profiled Bragg grating is fuzzy along the transverse coordinate. This is explained by finite size of the beams used for erasing the grating and measuring the reflected spectrum.

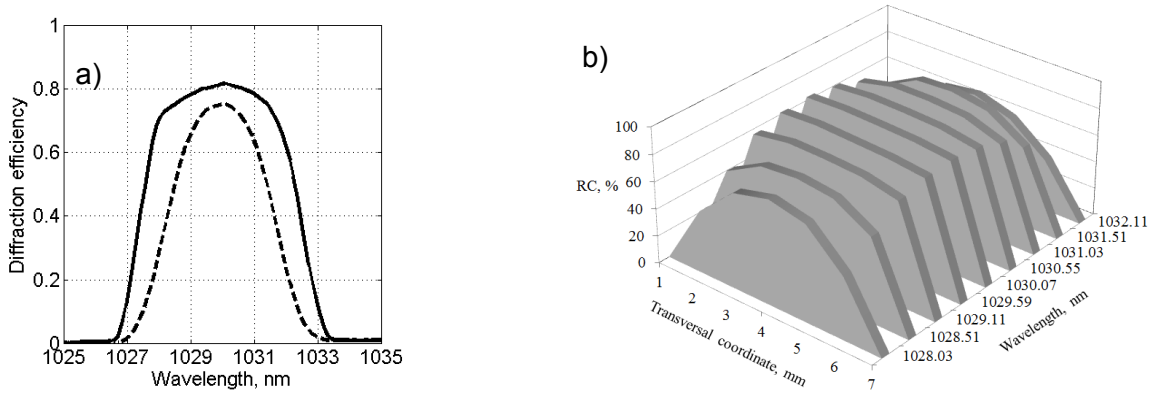

Fig. 17 a). Spectral shape of diffraction efficiency measured in the center (solid line) and 2 mm off the center (dashed line) of the 3D CBG aperture; b). Grating reflection coefficient as a function of transverse coordinate and wavelength.

If a beam with a diameter over 6 mm, uniform along transverse coordinates, with a rectangular spectrum having a width more than 6 nm is incident on such a grating, the reflected beam will have a

shape close to an ellipsoid.

First experiments on this new pulse shaping technique have been performed at IAP. A possibility to implement it at the upgraded ELLA laser is currently under studies. All these results are summarized in the paper S. Mironov et al. “Generation of 3D ellipsoidal laser beams by means of a profiled volume chirped Bragg grating” (milestone R-MS3).

4) Financial Plan / Time Schedule

Can you comply with the financial plan and time schedule or do you see a need for adjustment?

While only a small part of consumables had been spend in 2015 the experiences during the commissioning of the system after the installation helped to identify necessary modifications to improve the laser setup. A mayor equipment acquisition has been a new laser oscillator with an included laser amplifier. This new laser (Pharos-20W-1MHz) has been ordered in 2016 and will be delivered and installed at PITZ in the middle of April of 2017. In addition, optics to build 3D spectrographs for first and fourth harmonics laser pulse characterization have been ordered in 2016, together with other linear and non-linear optics needed for optimized laser operation and as spare parts. Also, electronics needed for laser synchronization has been bought in 2016. Currently two PhD student positions are funded in the frame of the project. Both of them (P. Boonpornprasert and J. Good) are working actively on their tasks. It is reasonable to keep their positions until the end of the project (middle of 2017).

As planned, in 2016 the focus of the work had been on both, further development of the laser and redesigning of the system. Therefore, the characterization of the laser system on the optical side has been of great importance. But also experimental tests of the 3D pulse shaping with electron beam generated at the PITZ photo injector have been done in 2016 and are ongoing since.

It seems to be realistic to achieve the original goals of the project - to upgrade the laser system for 3D-ellipsoidal shaped laser pulses, to fix critical issues revealed during its commissioning and to test the updated system with photoelectron beam production at PITZ.

5) Publications of the Group

[1] T. Rublack, J. Good, M. Khojoyan,M. Krasilnikov, F. Stephan DESY, Zeuthen, Germany; I. Hartl, S. Schreiber, DESY, Hamburg, Germany; A. Andrianov, E. Gacheva, E. Khazanov, S. Mironov, A. Potemkin, V.V. Zelenogorskii, IAP/RAS, Nizhny Novgorod, Russia; E. Syresin, JINR, Dubna, Russia, “Production of quasi ellipsoidal laser pulses for next generation high brightness photoinjectors”, NIM A, Volume 829, 2016, Pages 438–441.

[2] E.I. Gacheva, S.Yu. Mironov, A.K. Poteomkin, V.V. Zelenogorsky, A.V. Andrianov, E.A. Khazanov, M. Krasilnikov, F. Stephan, "3D ellipsoidal beam shaping in laser drivers for photoinjectors", LASER OPTICS (LO) 2016 INTERNATIONAL CONFERENCE, proceedings, 2016, 7549761.

[3] S. Yu. Mironov, A. K. Potemkin, E. I. Gacheva, A. V. Andrianov, V. V. Zelenogorskii, M. Krasilnikov, F. Stephan, and E. A. Khazanov, "Shaping of cylindrical and 3D ellipsoidal beams for electron photoinjector laser drivers," Appl. Opt. 55, 1630-1635 (2016)

[4] S. Yu. Mironov, A. K. Potemkin, E. I. Gacheva, A. V. Andrianov, V. V. Zelenogorskii, M. Krasilnikov, F. Stephan, and E. A. Khazanov, “Generation of 3D ellipsoidal laser beams by means of a profiled volume chirped Bragg grating” Laser Phys. Lett. 13, 055003 (2016)

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FEL electron bunches", Physics of Particles and Nuclei Letters, 2016, Vol. 13, No. 3, pp. 384–389.

[6] C. Hernandez-Garcia, M. Krasilnikov, G. Asova, M. Bakr, P. Boonpornprasert, J. Good, M. Gross, H. Huck, I. Isaev, D. Kalantaryan, M. Khojoyan, G. Kourkafas, O. Lishilin, D. Malyutin, D. Melkumyan, A. Oppelt, M. Otevrel, G. Pathak, Y. Renier, T. Rublack, F. Stephan, G. Vashchenko, Q. Zhao, "Studies on charge production from Cs2Te photocathodes in the PITZ L-band normal conducting radio frequency photo injector", Submitted on 1 Jul 2016, https://arxiv.org/abs/1607.00295

[7] C. Saisa-ard "Evaluation of the photocathode laser transverse distribution", PITZ internal note, https://pitz.desy.de/publications/internal_reports_and_information/

6) External Funding

The first prototype of the laser system was funded within the BMBF project (05K10CHE) "Developing a laser system for experimentally investigating the possibility to achieve quasi 3D ellipsoidal laser pulses" in the framework of the German- Russian collaboration "Development and Use of Accelerator-Based Photon Sources". IAP (Russia) and PITZ (DESY) are providing laser and accelerator infrastructures for the advanced laser system developments and tests including manpower for installation works, electronic and mechanic workshop capacities, support from the control group, operation time at the accelerator including electricity costs, personnel and on-call service.

Components - optical (crystals, Pockels cells) and electronical (uTCA timing boards) - in sum of 18 kEuro were covered in 2016 from the main PITZ budget. The participants from the Helmholtz Association side - PITZ staff (M. Krasilnikov, T. Rublack, J. Good, Y. Renier, F. Stephan and M. Gross) contribute part of their working time to the project. For the beam dynamics (mainly performed by Y. Renier) and IR/THz radiation simulations (done by P. Boonpornprasert) the computing capacities of DESY as well as operation resources for dedicated experimental program (funded by the internal PITZ sources) were used. IAP is actively using the existing laser infrastructure and available manpower for the project developments and tests. The works at JINR on a test bench for a high power laser driver applied for an FEL with high average power radiation mode are funded from internal sources of the institute.

7) Patent Applications

No. of pending/granted patents

No patent applications.

8) Awards received by Group Members

none