Summary of the 10th Direct Drive and Fast Ignition Workshop

Direct Drive and Fast Ignition Workshop is a traditional annual meeting devoted mainly to theoretical aspect of laser-driven inertial fusions, designed for future energy production (IFE). 10th edition was organized in Prague on May 27-30, 2012 under support of ESF RNP SILMI and CTU in Prague with participation of 28 speakers and 17 other participants, mainly young scientists and scientists moving from neighboring areas to this field. The participation exceeded expectation mainly due to extension of the community in Prague connected with the new large scale European infrastructure ELI-Beamlines Facility under construction in Prague.

Workshop included 4 long (1-hour) presentations that included also tutorial part meant mainly for young scientists and newcomers to the field. Program has also included 3 panel discussions devoted to present state and situation and future prospects, including detailed discussions on present problems of indirect fusion on NIF and perspective of the European HiPER program. Professor Joachain has also presented details about SILMI programme of ESF.

The program included fast ignition by laser generated hot electrons, both in geometry with cone and without cone. This option was previously meant as the main option for HiPER project however the attention now shifts to the shock ignition as a novel prospective scheme of ignition. The shock-generating spike of laser pulse can be formed by pulse-shaping capability of modern nanosecond lasers as the spike is longer and less intense than for fast ignition. Recent experimental and simulation results indicate surprisingly good absorption of the laser spike however the physics is less understood. Fast ignition by laser accelerated ions and impact ignition were discussed as alternative schemes of ignition.

Polar direct drive was analyzed as a possibility of direct drive research on NIF and LMJ facilities that are primarily designated to indirect drive research. Progress in studies concerning hydro-instabilities in fusion targets and fuel mixing was also presented, as well as studies of physics of laser-plasma interactions and novel methods in numerical simulations.

The workshop has also contributed to deepening and broadening of contacts and collaborations and also to incorporation of new members into the community. The presentations were posted on the workshop web page and are accessible for the workshop participants.

Scientific content of the 10th Direct Drive and Fast Ignition Workshop

First session of the workshop was devoted mostly to electron-driven fast ignition (EFI). Prof. Evans (Imperial College, UK) presented tutorial on electron acceleration and transport together with theoretical results of his group. Despite various mechanisms participate in hot electron generation and their relative importance is often difficult to estimate the absorption efficiency is generally high at intensities above 10^{19} W/cm^2 and thus absorption fraction is not the main concern. The main problem is the energy transfer to the compressed core. He stressed that experimental characterization of electron transport is difficult and interpretation of most experiments rely heavily on numerical simulations. Divergence and collimation of the electron beam depends on interplay of instabilities, we have excellent qualitative understanding however the predictive capability is limited. The prospects of building HiPER laser for studies of inertial fusion for energy production (IFE) seem very distant because of interest in HEDP (high energy density physics) and indirect drive in UK and France. Dr. Fedosejevs (Univ. Alberta, Canada) reported on recent experiments on fast electron generation and transport at 2ω on Titan laser at LLNL, USA. Absorption and electron yield was lower than at basic frequency as expected for lower $I\lambda^2$. Hot electron scaling looks good inside the target but major issue is large electron divergence angle (36° - 54°from K-α imaging). Dr. Ramakrishna (HZDR, Dresden, Germany) presented simulation and experimental results on collimation of electron beam in targets with special structures and in foam targets. These targets support formation of large magnetic fields that collimate fast electrons, collimation to 50 μm was illustrated without any significant loss in transport efficiency. This scheme has the potential to solve the divergence problem in transporting hot electrons into the core of compressed targets. Dr. Temporal (UPM Madrid, Spain) referred about theoretical results and numerical simulations on the advantages of using polarized DT fuel in direct drive and fast ignition inertial fusion. Polarized fuel would be generally very helpful but discussion reveals but the main problem is the survival of the polarization in the interaction chamber up to the ignition of fusion. Dr. Cornet (CEA, France) referred on novel hybrid PIC-MHD method for numerical simulation of laser interactions with dense targets that might be useful especially for studies of hot electron transport. The classical PIC method is used for low density outer part of target while in high density collision dominated plasma PIC is used for particles and electric field is calculated from Ohm's law. Mutual consistence of both attitudes was secured and transition zone was used to remove spikes in electric field. However it leads to certain artificial cooling of electrons. However, it seems to be first successful (at least partly) application of such idea. Prof. Joachain (Univ. Brussels) made a very detailed presentation of the ESF Research Networking Programme "SILMI" supporting science in this particular field.

Second session (Monday afternoon) was devoted mainly to ion fast ignition (IFI). Dr. Schlegel (GSI and HI Jena, Germany) presented talk on fast ignition with ponderomotively accelerated ions including tutorial on methods ion fast ignition. While most of IFI methods rely on external targets for ion acceleration, the method proposed by dr. Schlegel relies on ion acceleration in channel formed by intense circularly polarized channel in corona. This leads to a very simple target and interaction geometry suitable for high repetition operation but requires very high intensity of laser beam. Prof. Kawata (Utsunomiya Univ., Japan) presented possibility to increase ion acceleration efficiency together with improvement of their energy spectrum and divergence by using a sequence of laser pulses. Prof. Andreev (MBI Berlin, Germany) presented his theoretical work on improvement of ion acceleration efficiency by nanostructure target and on its application in fast ignition context. Dr. Ter-Avetissyan (IoP Prague) presented his results from MBI Berlin on acceleration on negative ions in cluster targets in direction normal to laser beam due to fast charge exchange.

Dr. Korn (IoP Prague) presented ELI (Extreme Light Infrastructure) project as distributed European research infrastructure and in details ELI Beamlines Facility under construction in the Czech Republic near to Prague and informed about the proposed pilot experiments.

A very interesting panel discussion the end of day was opened by summary prepared by Prof. Evans who summarized the status of EFI research and issues that should be solve for a reliable concept of HiPER. Despite the basic difference in ignition method, the present situation is negatively influenced by the problems in demonstration of indirectly driven inertial fusion at NIF laser in USA. Prof. Murakami informed the audience about closed meeting of selected invited international scientists in Livermore just before DDFIW in search of solution of problems at NIF. Despite the laser NIF laser itself is working perfectly the interaction and target physics is below the expectations of the programs carefully prepared via numerical simulations pointing to the fact the applied description of some physical processes was not accurate enough. Up-to-now, the attempts for improvements in target and interaction design have not been successful. We have also discussed how to improve our understanding of EFI and IFI via experiments, theoretical model and numerical simulations.

Tuesday morning session was devoted mainly to the shock ignition (SI). The tutorial was presented by Dr. Ribeyre (CELIA Bordeaux, France) who also presented his research on evolution of the converging shock wave, shock wave generation by fast electrons and on symmetry requirements for shock ignition. Dr. Canaud (CEA, France) presented the detailed strategy for demonstration of SI on the LMJ facility under construction in France. Polar Direct Drive (PDD) will be optimized at LMJ and detailed preparatory experiments will be at OMEGA laser in USA and Orion in UK. Dr. Brandon (CEA, France) reported on extensive set of 1D simulations leading to the design of baseline target for shock ignition. Prof. Murakami (ILE Osaka, Japan) proposed interesting modalities for reaching ultrahigh dense projectile acceleration for impact ignition, presented his analytical model and preliminary experimental results. Mr. Davie (Imperial College, UK) presented his simulations on reflection of perturbed shock waves relevant to shock ignition with the basic conclusion that perturbations do not destroy spherical behavior of the shock front. Mr. Levy (CEA, France) presented his results on the impact of self-generated magnetic field on Raleigh-Taylor instability. Though self-generated fields in the acceleration phase may reach more than 1 T, their effect on the instability is moderate, and their impact in deceleration phase is negligible.

The afternoon session was devoted to physics of laser interaction with long corona relevant to shock ignition (SI). The tutorial overview was presented by Prof. Tikhonchuk (CELIA Bordeaux), the simulation results predict up to 70% absorption of the shock-driving spike of laser pulse, hot electron temperature at level 30 keV, early saturation of TPD and competition of SBS and SRS leading to SBS suppression. Dr. Klimo (CTU in Prague) presented his collisionless and collisional PIC simulations of parametric instabilities for SI. They predict dynamic cavitation in underdense plasma leading to SBS suppression, however they are still significant differences between the calculated spectra of the scattered light and measurements on OMEGA lasers indicating that our understanding of the process is still incomplete. Dr. Mašek (IoP Prague) reported on his Vlasov-Fokker-Planck simulations depicting the evolution of Raman cascade in long corona. Prof. Limpouch (CTU in Prague) reported on studies on laser interactions with low-density-foam layers that can be used for smoothing of inhomogeneities in target irradiation. Analytical model of the propagation of planar laser-supported ionizing heat wave in underdense foam was developed and efficient scheme for numerical simulations of laser interactions with foam layers was proposed. Prof. Gus'kov (LPI Moscow, Russia) analyzed possibility to use non-cryogenic fusion fuel for spark and fast ignition concentrating mainly on BeDT compound. His estimates indicate that it might be feasible to use such fuel in energetic IFE reactor leading to technological simplifications and lower target cost.

The scientific program of the day was ended by very interesting panel discussion on SI scheme with summary prepared by Prof. Tikhonchuk. The discussion led to conclusion that SI scheme looks very promising but our knowledge is still rather incomplete and further experiments are needed and planned at PALS, LULI and OMEGA for better understanding the interaction physics and also the shock generation and core heating. Further theoretical and simulation studies are needed for the design and interpretation of experiments and also for better understanding of constraints on SI.

Wednesday morning session with devoted to the additional aspects of laser interaction with targets. Dr. Pšikal (CTU in Prague) reported on simulations of ion acceleration in thin foils with micro-structured surface and on the experimental proof of this idea in collaborative experiment at GIST, Gwangju, Korea. Dr. Elkina (LMU Munich, Germany) reported on modeling of laser target interactions at extremely high intensities when the QED (quantum electrodynamics) effects have to be taken into account. This novel problem starts to gain crucial importance in connection with new generations of lasers under construction (Apollon in France and ELI Beamlines in Czech Republic). Prof. Badziak (IPPLM Warsaw, Poland) reported on enhancement of ion and macroparticle acceleration by using a suitable micro-cavity and on the possibility to use such scheme for impact ignition. Prof. Liska (CTU in Prague) reported on numerical simulations of mixing and interpenetrating flows which is difficult problem important for fast ignition schemes with cones. Mr. Laffite (CEA, France) reported on set of simulations on design of experiments directed to direct drive and shock ignition demonstration using PDD on LMJ. They concluded that suppression of asymmetries in foot of laser pulse is essential as imprint has to be avoided while huge asymmetries in laser spike in shock ignition are tolerable. Prof. Drška devoted his talk to positron and meson sources that can be provided by the new generation of lasers reaching ultrahigh intensities. In a short panel discussion the presented results were summarized by prof. Limpouch.

In the afternoon small group of participants visited PALS laboratory with subnanosecond kJ iodine laser and femtosecond 20 TW Ti:Sapphire laser. In the informal discussions during the workshop, the program of the ELI Beamlines facility in Prague was extensively discussed, possibilities for co-operation and for joining its team were proposed by several participants.

Scientific impact of the 10th Direct Drive and Fast Ignition Workshop

The workshop brought together specialists in theory and modeling of laser plasma interactions and inertial fusion from 9 European countries, Russia, Japan and Canada. It also enabled young scientists and newcomers to the field to gain insight and basic overview into the field. This is extremely important also in connection with formation of the teams of new facilities and lasers in Europe. For this purpose tutorial part was included in presentations of 4 leading specialist.

Workshop enabled exchange of very recent results in this fast progressing field. The format enabled to present speakers not only final results but also preliminary results and research in progress. The less formal format also enables presentation of technical aspects that are usually omitted in journal articles and contribution on large conferences. Moreover, there was more time for the discussions and many comments and ideas presented by leading specialists were extremely useful both for the authors, and for the audience. Many new ideas for future extension of the presented research were presented.

The workshop has evaluated the status of the modalities of inertial fusion for energy production (IFE). It identified that the recent skepticism about fast ignition by fast electrons is not fully substantiated and there still exists a good chance that this method will enable to ease the parameters of laser for the ignition and IFE. The ignition by fast ions and impact ignition are still less known methods and their prospects look more distant than for other methods. Though the recent enthusiasm for shock ignition is partly due the novelty of this attitude and relatively small experience, this method looks very sound especially in the light of very high absorption of shock-generating spike found both experimentally and theoretically. Great advantage of the method is absence of necessity of special laser for short pulses as the spike may be obtained by pulse shaping of nanosecond lasers. Very relevant experiments are conducted at OMEGA laser in USA but it is important to assess the physical details at smaller European lasers. It is very important that theoretical design of possible large-scale demonstration experiments on NIF and LMJ has already started, as the optimization process is long and time consuming. Some novel ideas like using low-density foam layers for beam smoothing and non-cryogenic fuel could improve chances of both classical direct-drive spark ignition and of shock ignition.

The workshop has also made an important contribution to identification of the main issues in the research that should be addressed both experimentally and theoretically. This enables participants to take active part in proposals and design of relevant experiments and also to addresses these issues in their theoretical research and numerical simulations.

The workshop has also pointed to the weak points of the presently used simulation codes and possible methods for improvement were discussed. The presented novel simulation methods may serve as an inspiration how to improve and upgrade simulation codes developed by the participants and their teams.

Workshop has also contributed to the building of the community. The existing collaborations will be strengthened and novel collaborations have been started, new scientists have been incorporated into the community. This is presently very important for formation of new teams in connection with the start of new programs and facilities like Apollon laser in France and especially for the new joint large-scale European research infrastructure ELI Beamlines facility in Prague. Thus, Prague was very suitable place for the workshop and the knowledge about ELI Beamlines Infrastructure and chances there are opening there were communicated to the broader community of researchers.

Program of the 10th Direct Drive and Fast Ignition Workshop

Prague, May 27 – 30, 2012

Sunday May, 27

19:30 Registration

20:00 – 21: 30 **Welcome reception**

Monday, May 28

8:00 Registration

8:30 Opening

8:40 ***Joachain*** – ESF research networking programme "SILMI" (Super-intense laser-matter interactions)

Chair: V Tikhonchuk

9:00 ***Evans*** - Collisional PIC Simulations at Ultra-high Intensity (including tutorial overview on hot electron generation)

10:00 ***Fedosejevs*** - Fast electron generation and transport for fast ignition at 527nm

10:30 *Coffee break*

Chair: A. Andreev

11:00 ***Ramakrishna*** - Electron beam transport and collimation in structured targets

11:30 ***Temporal*** - Study of the ignition conditions of polarized DT for ICF

12:00 ***Cornet*** - A hybrid PIC-MHD model for high density lase r plasma simulations

12:30 *Lunch break*

Chair: M. Murakami

14:00 ***Schlegel*** - Fast Ignition with Ponderomotively Accelerated Ions (including tutorial overview on ion fast ignition)

15:00 ***Kawata*** - Multi-stage laser ion acceleration

15:30 ***Andreev*** - Fast ions generation from nanostructure target irradiated by high intensity short laser pulse

16:00 *Coffee break*

Chair: B. Canaud

16:30 ***Ter-Avetissyan*** - Energetic neutral and negative ion beams accelerated from spray target irradiated with ultra-short intense laser pulses

17:00 ***Korn*** - Research and technology development with ultra-intense lasers at ELI-Beamlines-Prague

17: 30 ***Panel discussion***

Tuesday, May 29

Chair: R. Evans

8:30 ***Ribeyre*** - Shock ignition and converging shock evolution (including tutorial overview on shock ignition)

9:30 ***Canaud*** - Towards Direct-Drive Shock-Ignition on the Laser Megajoule

10:00 ***Brandon*** – 1D baseline target design for direct drive shock ignition

10:30 *Coffee break*

Chair: S. Gus'kov

11:00 ***Murakami*** - High compression of matter by hyper-spherical shockwaves and its implication to ICF

11:30 ***Davie*** - Perturbed Reflected Shocks relating to the Shock Ignition IFE Scheme

12:00 ***Levy*** – Self-Generated Magnetic Fields and Rayleigh-Taylor Instability

12:30 *Lunch break*

Chair: S. Kawata

14:00 ***Tikhonchuk*** – Laser interactions with long corona relevant to SI (including tutorial overview)

15:00 ***Klimo*** - Modeling laser plasma interaction in shock ignition

15:30 ***Mašek*** - Vlasov-Fokker-Planck simulations of electron gas in long scale length laser plasmas

16:00 *Coffee break*

Chair: J. Badziak

16:30 ***Limpouch*** - Foams in DD fusion: Laser-supported ionization wave in gases and foams

17:00 ***Gus'kov*** - Non-cryogenic fast- and shock-ignited ICF targets

17: 30 ***Panel discussion***

19:45 **Workshop dinner** ***(Restaurant Petřínské terasy – please, see additional instructions)***

Wednesday, May 30

Chair: T. Schlegel

8:30 ***Pšikal*** – Proton acceleration in thin foils with micro-structured surface

9:00 ***Elkina*** - Multi-scale modeling of laser-plasma interaction at ultra-high intensity

9:30 ***Badziak*** - Efficient acceleration of ion beams and macroparticles for fast ignition in the LICPA accelerator

10:00 ***Liska*** - Hydrodynamics simulation of interpenetrating laser generated plasma plumes

10:30 *Coffee break*

Chair: X. Ribeyre

11:00 ***Laffite*** - Symmetry in a 48 beams Direct Drive configuration

11:30 ***Drška*** - Laser-driven Positron and Meson Generation

12:00 ***Panel discussion***

12:30 *Lunch break*

14:00 Optional – ***Excursion to PALS laboratory or Discussion at IoP AS CR***