11th Workshop on Direct-Drive and Fast Ignition Physics [1]

Rome, May 6th – 8th , 2013

Facoltà di Ingegneria
Auletta del Chiostro di San Pietro in Vincoli

FINAL REPORT

Summary

The *Direct Drive and Fast Ignition Workshop* is an annual meeting of specialists on theory and simulations of interaction of intense laser beams with targets and direct drive inertial fusion. A few leading experimentalists are also invited to report on the latest important experiments. The 11th edition of the Workshop was held in Rome, on May 6th – 8th, 2013, organized by Dipartimento di Scienze di Base e Applicate (SBAI), Università di Roma "La Sapienza", and chaired by S. Atzeni.

The focus of the workshop was on the physical modelling required for predictive simulation of experiments on the advanced direct-drive inertial fusion schemes known as "shock ignition" and "fast ignition". Emphasis was on the development of new models, guided by comparison with experiments, and on the identification of possible experiments to be performed in the next few years at European Large Scale Facilities.

The workshop was attended by 33 scientists (including 6 graduate students and 8 young post-docs) from 8 European countries. The programme included 24 talks 20–30 minute long, and 4 open discussions on topic of emerging interest (fluid modelling needs for target design as required by the HiPER project; plasma instabilities and their modelling; future experiments at European Large Scale Facilities; status of fast ignition physics). Demonstration of 300 Mbar shock pressure, understanding and control of laser-plasma instabilities (and related cross-beam-energy transfer), and modelling of hot electron transport were identified as the key issues for shock ignition. It was also agreed that control of electron beam divergence by magnetic fields is an outstanding issue for fast ignition.

Finally, it should also be remarked that the interaction between theorists, computational physicists and experimentalists as well as between senior and junior scientists proved extremely fruitful, and resulted in a lively meeting.

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[1] Organised by Dipartimento SBAI, Università di Roma *La Sapienza* and CNISM
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Scientific content and discussions

The 11th Workshop on Direct-Drive and Fast-Ignition addressed a few key issues concerning the predictive modelling of inertial confinement fusion (ICF) experiments. In particular, it focussed on the advanced ignition schemes known as shock ignition and fast ignition. Indeed, such schemes have attracted considerable attention in the past few years, because of their potentials for high energy gain, and hence for applications to fusion energy production.

Both such schemes are direct-drive laser fusion schemes. However, differently from the conventional inertial fusion scheme, the stages of fuel compression and hot spot ignition are separated. A first laser pulse drives fuel compression at velocity somewhat lower than in conventional ICF. A second pulse causes ignition of the precompressed fuel. In shock ignition an intense pulse (irradiating a large portion of the compressed fuel) drives a strong converging shock wave which creates a central hot spot. In fast ignition, an ultraintense, tightly focused pulse generates relativistic electrons, which in turn should create the ignition hot spot. Both such schemes have potentials for achieving ignition at lower laser energy and high gain at given laser energy than conventional schemes. However, they also involve novel issues.
In particular, shock ignition requires understanding and control of laser plasma instabilities (LPI) that may occur during the irradiation of the target by the shock-creating pulse. It has to be proved that the laser pulse can generate efficiently the required strong shock. Fast ignition requires efficient production and transport of a focused beam of electrons with energy in a well defined narrow range (and experiment so far show excessive beam divergence) . The workshop focused just on these issues, as they play a crucial role in the studies of concepts pursued by the HiPER project (addressing Laser Fusion in the frame of the European ESFRI roadmap). However it also paid attention to the recent results from the conventional ICF experiments at the National Ignition Facilities, which showed the importance of proper modelling laser-plasma instabilities and of accurately controlling target illumination uniformity.

Presentations and discussions were grouped by topic, as follows:

Monday morning:
i) symmetry and stability in ICF, particularly in direct-drive
ii) hydrodynamics of shock ignition targets

Monday afternoon
iii) electron transport effects on shock ignition
iv) general discussion on fluid modelling for shock ignition.

Tuesday morning
v) Laser plasma instabilities, LPI (theory and experiments) and general discussion on LPIs

Tuesday afternoon
vi) Experimental results on laser-plasma interaction and general discussion on the next experiments at European Large scale facilities

vii) A tutorial on laser-driven ion acceleration

Wednesday morning

viii) Electron acceleration and transport in ultraintense laser-plasma interaction
ix) General discussion on fast ignition.

The presentations and discussions on hydrodynamics and symmetry showed impressive progress in the capability of 3D modelling (Chittenden). It seems that 3D models can help to explain so far incompletely understood experimental NIF results. On the other hand, 2D codes still prove invaluable tools for parametric design studies (Scott, Delorme). Many speakers discussed code upgrades (for 3D ray-tracing, hot electron transport, nonlocal electron transport: Schiavi, Marocchino, Gus'kov) as well as application to target design for shock ignition (Atzeni, Le Bel). Models for target scaling, in principle allowing for the design of targets for the demonstration of shock ignition in the next decade have been presented. The lively discussion on hydrodynamic modelling, however, emphasized the need for i) experimental validation of transport models; ii) development of models for cross-beam-energy-transfer; iii) understanding of the limitation of codes based on simple collisional laser-matter interaction.

LPIs in the context of shock ignition were reviewed by V. Tikhonchuk, while a few presentations (Goyon, Baffigi) addressed specific topics. S. Huller presented an innovative laser irradiation scheme, that may avoid the insurgence of LPIs. It is based on laser pulses formed by spikes of uneven duration and delay (STUDD). This talk provoked interesting discussions. Participants raised questions about the actual technical feasibility of this potentially revolutionary approach to LPI suppression. In any case, it appears that LPIs deserve increased modelling effort.

Batani reported on the construction of the lasers PETAL and LMJ (CESTA, Bordeaux), and on the experimental opportunities they will offer in a few years. Given the size and complexity of the facilities, accurate design will be needed, and this will require large collaborative efforts.

A few talks concerned ion acceleration (with a broad spectrum review by Macchi, and more specific presentations by Limpouch and Raczka) and diagnostics of charged particles (Consoli).

A series of talks addressed generation and transport of relativistic electrons in ultra-intense laser – plasma interaction (Vranic, Koester, Volpe, Schlegel, Sherlock). These were followed by a discussion on fast ignition. It was made clear that all efforts on fast ignition have to be devoted to the development of schemes allowing for reducing beam divergence. This is the first experimental goal, which can be tackled even on the present relatively small scale facilities. In case of success,

Assessments of the results and impact on the future direction of the field

Presentations and discussions at the meeting lead to the clear identification not only of key issues for shock and fast ignition, but also of urgent modelling and validation needs. A particular contribution to the achievement of this goal came from the interaction between theorists, experts in simulations and experimentalists. It is also hoped that the young scientists could profit from the wider-scope presentations and contributions to the discussions by the participating senior scientists.

Important result concerns hydrodynamic modelling. On one hand they are invaluable: 3D codes provide unique clues for the interpretation of experimental results. 2D codes are essential for parametric design studies accounting for asymmetries and instabilities. However, i) They need to be upgraded to include features which may be important in the study of shock ignition targets (3D irradiation, non local electron transport, …). ii) It has to be proved that fluid models are still appropriate at the intensity of the shock ignition pulse. (If not one has to use some form of kinetic-fluid integrated approach). Only experiments can resolve the above issues. iii) so far, no 2D code includes a first-principle model for cross-beam energy transfer, a phenomenon clearly observed in a few experiments.

Progress in LPI is noteworthy, as is the effort currently devoted to them. However, again, experiments are required at intensity and plasma scales relevant to shock ignition. The STUDD scheme also deserves (at least on a small scale) technical implementation to demonstrate its potentials.

In view of the above experimental need, and of the future availability of the LMJ and PETAL facilities, it is urgent to start collaborations to envisage and design relevant experiments, to address key issues for shock ignition at the proper, ignition relevant scale.

On relativistic electron generation and transport talks have shown progress both in modelling and in experiments. The next generation of experiments (assisted by suitable modelling) will be devoted to demonstrating the feasibility of schemes for reducing the divergence of the electron beam, by using magnetic fields (either pre-imposed or self-generated).

In conclusion, the workshop led to a clear identification of research themes to be pursued, in a collaborative framework, in the next few years.

Annexes

1. Programme
2. List of participants

11th Workshop on Direct-Drive and Fast Ignition Physics [2]
Rome, May 6th – 8th, 2013

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Monday, May 6th

8.30 – 9.15	Registration
9.15 – 9.30	Opening, welcome and practical information (S. Atzeni, A. Marocchino)

Chair: V. Tikhonchuk

9.30 – 10.00	J. Chittenden, Imperial College, London *The role of three-dimensional asymmetry during the deceleration phase and in inhibiting ignition*
10.00 – 10.20	A. Schiavi, Università di Roma "La Sapienza" *Start-to-end direct-drive 2D simulations with accurate 3D raytracing*

Chair: T. Schlegel

10.50 – 11.10	R. Scott, STFC Rutherford Appleton Laboratory *Numerical modelling of the sensitivity of x-ray driven implosions to low-mode flux asymmetries*
11.10 – 11.30	B. Delorme, CELIA, Université de Bordeaux-1 *Analysis and simulation of ablative Richtmyer-Meshkov direct-drive experiments at the OMEGA laser*
11.30 – 12.00	S. Atzeni, Università di Roma "La Sapienza" *Energy scaling of shock ignition targets: options for increasing target robustness*
12.00 – 12.20	E. Le Bel, CELIA, Université de Bordeaux-1 *Target design model for shock ignition experiments on MJ class laser*

Chair: J. Chittenden

14.15 – 14.45	S. Gus'kov, P. N. Lebedev Physical Institute, Moscow *Igniting shock wave driven by high energy electron stream*
14.45 – 15.05	A. Marocchino, Università di Roma "La Sapienza" *Nonlocal electron transport: modelling and effect on 1D and 2D shock ignition simulations*
15.05 – 16.00	*Meeting of the Italian project PRIN 2009 on the physics of shock ignition*
16.00 – 17.00	*Discussion on fluid models, experimental validation, target design as required by the HiPER roadmap for shock ignition demonstration* (moderators: S. Atzeni, S. Gus'kov)
20.00	Social dinner

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Tuesday, May 7th

Chair: J. Limpouch

9.00 – 9.30	V. Tikhonchuk, CELIA, Université de Bordeaux-1 *Laser-plasma interaction physics for the shock-ignition conditions*
9.30 – 9.50	C. Goyon, CEA *Interaction on picosecond scale for shock ignition scheme of inertial fusion*
9.50 – 10.10	S. Hüller, CPT, Ecole Polytechnique, Palaiseau *Control of laser-plasma instabilities using spike trains of uneven duration and delay (STUDD)*
10.40 – 11.00	F. Baffigi, INO-CNR, Pisa *Investigation of optical scattering in shock ignition relevant conditions*
11.00 – 11.20	L. Antonelli, Università di Roma Tor Vergata *Intense shock wave experiments at PALS*
11.20 – 12.20	*Discussion on laser-plasma instabilities and relevant modelling* (moderator: V. Tikhonchuk)

Chair: L. Gizzi

14.00 – 14.30	D. Batani, CELIA, Université de Bordeaux-1 *Status of PETAL and LMJ laser facilities*
14.30 – 15.00	A. Macchi, INO-CNR, Pisa *Recent results in laser-driven ion acceleration*
15.00 – 15.20	J. Limpouch, Czech Technical University, Prague *Laser-induced ion acceleration and fast ignition*
15.40 – 16.00	F. Consoli, ENEA, CR Frascati, Italy *Diagnostics of p ^{11}B low-rate fusion reactions in nanosecond laser plasmas*
16.00 – 16.20	P. Raczka, Institute for Plasma Physics and Laser Microfusion, Warsaw *Cavity-enhanced laser-driven acceleration of intense ion beams for ion fast ignition*
16.20 – 17.00	*Discussion on future joint experiments at European facilities* (moderator: D. Batani)
17.00 – 17.45	*Meeting of the collaboration on shock-ignition experiments at PALS*

Wednesday, May 8h

Chair: R. Evans

9.20 – 9.40	M. Vranic, Instituto Superior Tecnico, Lisbon *Simulations of laser channelling and fast electron generation in realistic density gradients*
9.40 – 10.00	P. Koester, INO CNR, Pisa *Enhanced energy deposition in a scheme of counter-propagating fast electron beams – The role of plasma instabilities*
10.00 – 10.20	L. Volpe, CELIA, Université de Bordeaux-1 *Fast electron guiding using two consecutive laser pulses*

Chair: S. Atzeni

10.40 – 11.00	T. Schlegel, GSI, Darmstadt *The role of the hot electron distribution in TNSA ion acceleration*
11.00 – 11.20	M. Sherlock, Imperial College, London *The role of fast-electron-generated wake fields in heating solid targets irradiated by short pulse lasers*
11.20 – 12.20	*Discussion on fast ignition physics* (moderator: Gizzi)
12.20 – 12.30	*Closing remarks*

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Final list of participants

1	Luca	**Antonelli**	Università di Roma "Tor Vergata", Italy
2	Tony	**Arber**	University of Warwick, UK
3	Stefano	**Atzeni**	Università di Roma "La Sapienza", Italy
4	Federica	**Baffigi**	CNR/INO, Pisa, Italy
5	Dimitri	**Batani**	CEA/CELIA, Université de Bordeaux-1, France
6	Jeremy	**Chittenden**	Imperial College, London, UK
7	Fabrizio	**Consoli**	ENEA, CR Frascati, Italy
8	Gabriele	**Cristoforetti**	CNR/INO, Pisa, Italy
9	Chris	**Davie**	Imperial College, London, UK
10	Riccardo	**De Angelis**	ENEA, CR Frascati, Italy
11	Barthélémy	**Delorme**	CEA/CELIA, Université de Bordeaux-1, France
12	Roger	**Evans**	Imperial College, London, UK
13	Leonida Antonio	**Gizzi**	CNR/INO, Pisa, Italy
14	Clément	**Goyon**	CEA, France
15	Sergey	**Gus'kov**	P. N. Lebedev Phys. Inst., Moscow, Russia
16	Stefan	**Hüller**	Centre de Physique Theorique, Ecole Polytechnique, Palaiseau, France
17	Petra	**Koester**	CNR/INO, Pisa, Italy
18	Livia	**Lancia**	Università di Roma "La Sapienza", Italy
19	Edouard	**Le Bel**	CEA/CELIA, Université de Bordeaux-1, France
20	Jiri	**Limpouch**	Czech Technical University, Prague, Czech Republic
21	Andrea	**Macchi**	CNR/INO, Pisa, Italy
22	Alberto	**Marocchino**	Università di Roma "La Sapienza", Italy
23	Piotr	**Raczka**	Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland
24	Maria	**Richetta**	Università di Roma "Tor Vergata", Italy
25	Angelo	**Schiavi**	Università di Roma "La Sapienza", Italy
26	Theodor	**Schlegel**	GSI, Darmstadt, Germany
27	Robbie	**Scott**	STFC Rutherford Appleton Laboratory, UK
28	Mark	**Sherlock**	Imperial College, London, UK
29	Vladimir	**Tikhonchuk**	CELIA, Université de Bordeaux-1, France
30	Giorgio	**Turchetti**	Università di Bologna, Italy
31	Laura	**Vassura**	LULI-Ecole Polytechnique and Università di Roma "La Sapienza"
32	Luca	**Volpe**	CELIA, Université de Bordeaux-1, France
33	Marija	**Vranic**	Instituto Superior Tecnico, Lisbon, Portugal