**Scientific Report of the 2nd Workshop on**

# *APPLICATIONS OF BRIGHT AND ULTRA-SHORT PARTICLE SOURCES WITH INTENSE TABLE-TOP LASERS*

Carre des Sciences, Paris, December 2nd - 4th, 2002

## *1. EXECUTIVE SUMMARY*

The goal of the workshop was to:

a) Disseminate information on the current status of particle sources generated with compact TW-laser systems.
b) Work out possible applications with future users not coming from the laser-plasma community.
c) Present this research to representatives from laser, conventional accelerator and medical industry.
d) Establish a new and interdisciplinary group of scientist.

Accounting for the interdisciplinary of this workshop (medicine, chemistry, plasma, nuclear, accelerator and astrophysicists), open discussions with all participants were emphasised. This enabled to build up new bridges between these separate communities during this workshop, whereas co-operations are now already on their way.

Initially, plasma physicists, who develop these unique sources, have discussed their performances. Within the same session scientists, using existing sources at conventional accelerators reported on their request. This was enhanced in an outlook on planned upgrades of these facilities to distinguish what will be possible to carry out in the near future in laser facilities.

Since a plasma is an ionised medium, it can support extremely high electric fields. Their peak values have been demonstrated to exceed several TV/m, which is about 4 - 5 orders of magnitude higher than those available in conventional accelerators. Due to this it is possible to generate a compact and unique particle source.
These plasmas are generated when a TW laser is focused onto a solid or gaseous target. Electron beams are typically produced using a gas jet; proton beams are obtained using a thin foil target; neutrons were seen with either one of them and in addition also with clusters.

It has been shown that ultra-short electron beams generated with a laser are of great interest for perfectly synchronised pump-probe experiment for material sciences and ultra-fast chemistry. Due to the high electron beam quality it can be used as an injector for conventional accelerators. Here, solely the number of high-energy electrons ought to be increased. However, recent numerical simulations have announced its feasibility proposing the so-called “light bullet” regime.

Using a high Z target, the electron beam can be in turn converted to a sub-millimetre $\gamma$ ray source, which is way smaller than those available today. This is of great interest for probing small defaults inside materials. Also, this radiation source is of use in medicine for radiotherapy. Finally, the interaction of second laser pulses with this electron beam can produce a multi-chromatic and ultra-short X-ray source. This unique source will be of interest for EXAFS studies. X-ray sources produced using a solid target are of interest for mammography. Here, a significantly enhanced contrast will be available when 2D of a few centimetre area frame grabber will be available that operates in the ps regime.

It has been shown that proton beams generated by lasers can be competitive with those produced by LINACs or synchrotrons machines. Medical and material applications have been pointed out.
For medicine two main applications have been proposed: First, protontherapy assisted by lasers. Here, the proton energies ought to be within the therapeutic window between 70 and 250 MeV. To reach this goal compact PW, high repetition rate lasers need to be developed. This will offer an economical proton source for several hospitals to treat cancer tumours. Therefore, this scheme will feature several major advantages: *(i)* It brings the treatment facility due to scale reduction from vast stand-alone cyclotron sites to the normal hospital environment. *(ii)* It enables easy beam orientation without expensive iso-centric gantries. *(iii)* It cuts down expenses and thus makes this superior treatment more widely available. *(iv)* Simultaneous in-beam imaging with the same device could be investigated (generation of radionuclides).
Secondly, medical applications are also foreseen concerning the production of short live-time radioisotopes for PET. For this purpose it has been concluded that a 100TW laser operating in the kHz regime will be needed.

Electron and proton beams with a pulse length in the ps or fs time-scale will provide an unique opportunity to study new and likely biological radiation effects.

Fundamental aspects of laser-plasma interaction in the relativistic regime have been mentioned. They cover fields such as astrophysics (MG magnetic fields and blast waves are currently generated with such lasers). In nuclear physics the reduction of the life-time of nuclei and transmutation are aimed at, as well as measurements of cross sections. The latter has so far not been retained due to the very high reproducibility required for this purpose. For plasma physics and fusion studies in the fast-ignitor scheme was discussed.

## *2. GOAL OF THE WORKSHOP*

Plasma physicists produce particle sources using compact "table-top" laser systems, which can be of severe benefit. Therefore, the aim of this workshop was to disseminate their feasibility to a large and broad community of scientist.

### *2.1 Motivation :*

It has been demonstrated in the last two years that short pulse "table-top" lasers can generate various particle sources. These bright sources of electrons, protons, $\gamma$ radiation and neutrons are reproducible and particularly their parameters (energy, brightness, emmittance, …) are easily adjustable to any needs for applications. Their generation compared to nowadays techniques is furthermore of lower cost, more efficient and thus feasible in many laboratories. We do believe that this opens up new opportunities in different fields such as medicine, chemistry and nuclear physics. The objective of this workshop is to specify applications of these sources in these fields.

### *2.2 Organisation :*

To reach this goal the workshop was organized as follows :

Plasma physicists have presented the "new particle sources" generated by lasers. One overview talk for each particle source was presented. Non-plasma physicists have introduced their research activities with the conventional particle sources. Finally, industrials have shown the state of art of accelerators, whilst laser physicists gave an outlook on near future perspectives of compact laser systems.

### *2.3 Workshop spirit :*

In order to keep the non-formal workshop spirit, ten minutes were consecrated at the end of each talk for open discussions. At the end of each day discussion around an open table for 1h 15min concluded and extended the topics of the day. To improve the communication between experts we have chosen the "one day – one particle source" strategy.

## *3. RESULTS OF THE WORKSHOP*

### *3.1 Summary of particle sources produced by lasers :*

<u>Electrons:</u>

It has been shown that electron beams produced with lasers have the following parameters : Broad spectra (it can be fitted by a Maxwellian function) with energies of up to 200 MeV. Electron effective temperatures clearly depend on the regime and are simply a function of the electron density. The normalized emmittance of this electron beam is below 3 $\pi$ mm mrad, which already fulfils standards in conventional accelerator physics. Around 1% of the laser energy is converted to hot electrons with energies above 1MeV. The electron beam, according to simulations is below 100 fs. Several regimes of interaction producing such electron beams have been presented: the Self-Modulated Laser Wake-Field, the Forced Laser Wake-Field and Direct Laser Acceleration. They are produced when focusing a TW laser beam onto a gas jet and/or and under-dense plasma.

Ions:

It was shown that proton and ion beams produced by lasers have the following parameters : Broad spectra with energies up to few tens of MeV. The ion (proton) beam effective temperature depends of the laser intensities. The normalized emmittance of this ion (proton) beam is even below 0.3 π mm mrad. The ion (proton) beam, according to simulations is shorter than a few ps. The number of protons depends strongly on the target material. It has been shown that there is an optimum thickness for producing higher energy protons. This optimum thickness depends of the laser pulse duration and of the laser contrast. A few % of the laser energy is converted in hot protons with energies above 1MeV. They are produced when focusing a TW laser beam onto thin foils or pre-exploded very thin foils.

X and γ rays:

Both X and γ-rays source sizes have been stressed to be the major advantages with classical sources. Their ultra-short duration (<100fs for the X-rays and less than few ps for γ-rays) is also of relevance for applications. Their spectra can be broad or mono-energetic. Recent results on Larmor radiation produced in the interaction focal volume and preliminary experiments on non Linear Thomson has been presented.

Neutrons:

Fusion neutrons with an energy around 2.45 MeV are currently obtained by focusing a TW laser onto solid targets, clusters (cooled or at room temperature) and gas jets.

### *3.2 Expected applications.*

Electrons and γ :

It has been stressed that ultra-short electron beams are of interest for fast-chemistry (e.g., radiolysis studies). γ ray sources, generated during the interaction of the electron beam with high Z materials, will be of interest for medicinal applications in radiotherapy, for high density radiography as well as non-destructive inspection of materials. For the latest application the sub-millimetre source size will be an enormous advantage to conventional γ millimetre source.

Ions:

It has been shown that such proton sources do require lasers operating in the kHz regime to be of any interest for the above mentioned medical applications. Another very important medical application has been discussed concerning the use of compact laser systems to deliver proton beam for proton-therapy. It has been concluded that a PW laser high repetition rate (few Hz) will be necessary to succeed in the production of proton beams with the required energies in the therapeutic window. Several points were discussed concerning the spectra: broad spectra can also be of interest for such purposes. Nevertheless, some ideas have been presented concerning the production of a mono-energetic proton beam. This scheme will permit to offer a compact and economical machines inside many hospitals. Applications in fundamental physic such as the fast-ignitor scheme for fusion and stopping power measurement in dense plasmas have been discussed.

X rays:

Major advances are expected with lasers for the production of ultra-short, broad X ray spectra. These sources will be very promising for EXAFS studies within sub-ps time resolution. For mammography application, the major advances are the increased contrast of the image, which permits to detect small sized cancer tumours.

Neutrons:

Here it has been shown that such sources, even though the number of neutrons is smaller than at accelerator facilities, can be of interest for material studies and for pump-probe experiment of short events.

Fundamental applications on laser-plasma interactions in the relativistic regime have been extensively discussed. They concerned astrophysics (blast waves, plasma fusion and huge magnetic fields) and nuclear physics (plasma and collective effect in the stopping power of particles).

## *4. ASSESSMENT OF THE RESULTS*

It has been clearly demonstrated that these "new particle sources" are of great interest because of their unique properties and their perfect synchronisation with a laser beam. The field of research and of interest is not anymore solely inside the plasma physicist community but enlarged to the entire scientific community. The increasing number of scientists interested in these sources clearly demonstrates the significance of this research. This workshop has been successful for European researchers since they have the last update on the state of art of particle sources produced with lasers and other technologies and their applications. This workshop will thus serve as a bridge, which has already established new European projects and collaborations.

## *5. FINAL PROGRAMME*

# Monday, 02 December 2002

8.30 - 9.00 Inscription
9.00 - 9.15 V. Kaucic, ESF/PESC (Slovenia)

**Electron Generation (Chairman : V. Malka)**

9.15 - 10.00 Electron Generation : An Overview on Experimental Results
S. Fritzler, LOA, Palaiseau (France)
10.00 - 10.45 Electron and Ray Generation : A Review of Theoretical Studies
E. Lefebvre, CEA, Bruyères-le-Châtel (France)

10.45 - 11.00 COFFEE

**Electron Application I (Chairman : C. Deutsch)**

11.00 - 11.45 Some Possible Trends in Irradiation Physics with Ultrashort Particle Bunches
G. Petite, SESI, Palaiseau (France)
11.45 - 12.30 Towards a Real Time Probing of Chemical Events during the Pre-thermal Phase of a Track Development
Y. Gauduel, LOA, Palaiseau (France)

12.30 - 14.00 LUNCH

**Medicine Session I (Chairman : J. Davies)**

14.00 - 14.45 Cancer Treatment
L. Schwartz, LPTP, Palaiseau (France)
14.45 - 15.30 What is Radiotherapy ?
P. Scalliet, University of Louvain (Belgium)

15.30 - 15.45 COFFEE

**Radiation Session (Chairman : J.C. Gauthier)**

15.45 - 16.30 Soft X Ray Generation using Laser-Plasma Interactions
A. Rousse, LOA, Palaiseau (France)
16.30 - 17.15 Experimental Observation on  Ray Generation
P. Norreys, RAL, Didcot (UK)

**17.15 - 18.00 Open Discussion**

# <u>Tuesday, 03 December 2002</u>

**Proton Session I (Chairman : M. Borghesi)**

9.00 - 9.45 Overview on Experimental Results
K. Krushelnick, Imperial College, London (UK)
9.45 - 10.30 Laser Induced Proton Beams - A Review -The Next Steps for Successful Applications to Medicine
K. Ledingham, University of Strathclyde, Glasgow (Scotland)

10.30 - 10.45 COFFEE

**Proton Session II (Chairman : P. Mora)**

10.45 - 11.30 Theoretical Perspectives on Proton and Neutron Generation
A. Pukhov, University of D¨usseldorf (Germany)
11.30 - 12.15 Protontherapy – Present Status and upcoming Challenges
R. Ferrand, CPO, Orsay (France)

12.15 - 14.00 LUNCH

**Medicine Session II (Chairman : P. Scalliet)**

14.00 - 14.45 Production of Isotopes by means of Laser Beams for Medical Applications: Which, why, how much
W. Pilloy, General Hospital, Luxembourg (Luxembourg)
14.45 - 15.30 Laser-Produced Hard X Rays for Medical Applications
S. Svanberg, University of Lund (Sweden)

15.30 - 15.45 COFFEE

**Accelerator Session (Chairman : D. Jaroszynski)**

15.45 - 16.30 The Electron Cyclotron Resonance Devices as a Source of Charged Particles
P. Sortais, IN2P3, Grenoble (France)
16.30 - 17.15 Activities at IBA
M. vander Donckt, IBA, Louvain-la-Neuve (Belgium)

**17.15 - 18.30 Open Discussion**

**20.00 French Dinner**

## Wednesday, 04 December 2002

**Laser Session (Chairman : J. Collier)**

9.00 - 9.45 New Developments for Petawatt Class Ti-Sapphire Femtosecond Lasers
J.P. Chambaret, LOA, Palaiseau (France)
9.45 - 10.30 Future Prospects for OPCPA in Compact High Average and peak Power (CHAPP) Lasers
Ross, RAL, Didcot (UK)

10.30 - 11.00 COFFEE

**Neutron Session (Chairman : Ph. Balcou)**

11.00 - 11.30 Neutron Generation with Solid Targets
S. Karsch, MPQ, Munich (Germany)
11.30 - 12.00 Clusters for Neutron Sources
R. Smith, Imperial College, London (UK)

12.00 14.00 LUNCH

**Astrophysics Session (Chairman : J.F. Chemin)**

14.00 - 14.45 Nuclear Astrophysics with High Intensity Lasers
A. Mohr, University of Darmstadt (Germany)
14.45 - 15.30 Quests for Astrophysics with High Intensity Lasers
B. Bingham, RAL, Didcot (UK)

15.45 - 16.15 COFFEE

**16.15 - 18.00 Discussion and Workshop Conclusions**

## *5 FINAL LIST OF PARTICIPANTS*

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B : 40-50 years old
C : 30-40 years old
D :younger than 30.

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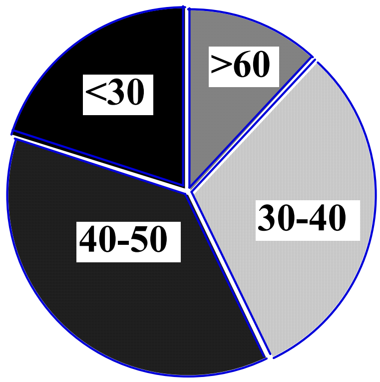
## *6. STATISTICAL INFORMATION*

**Age bracket :**



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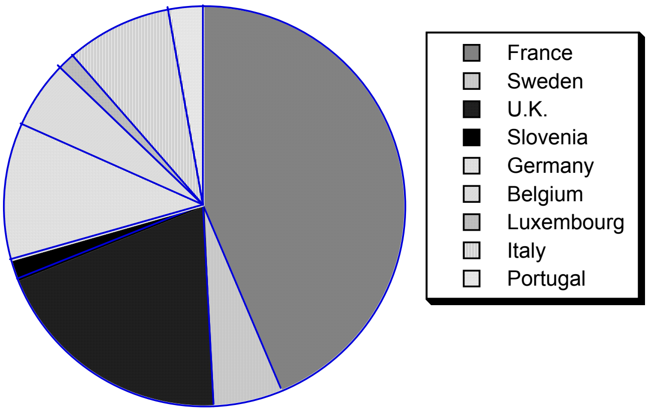


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